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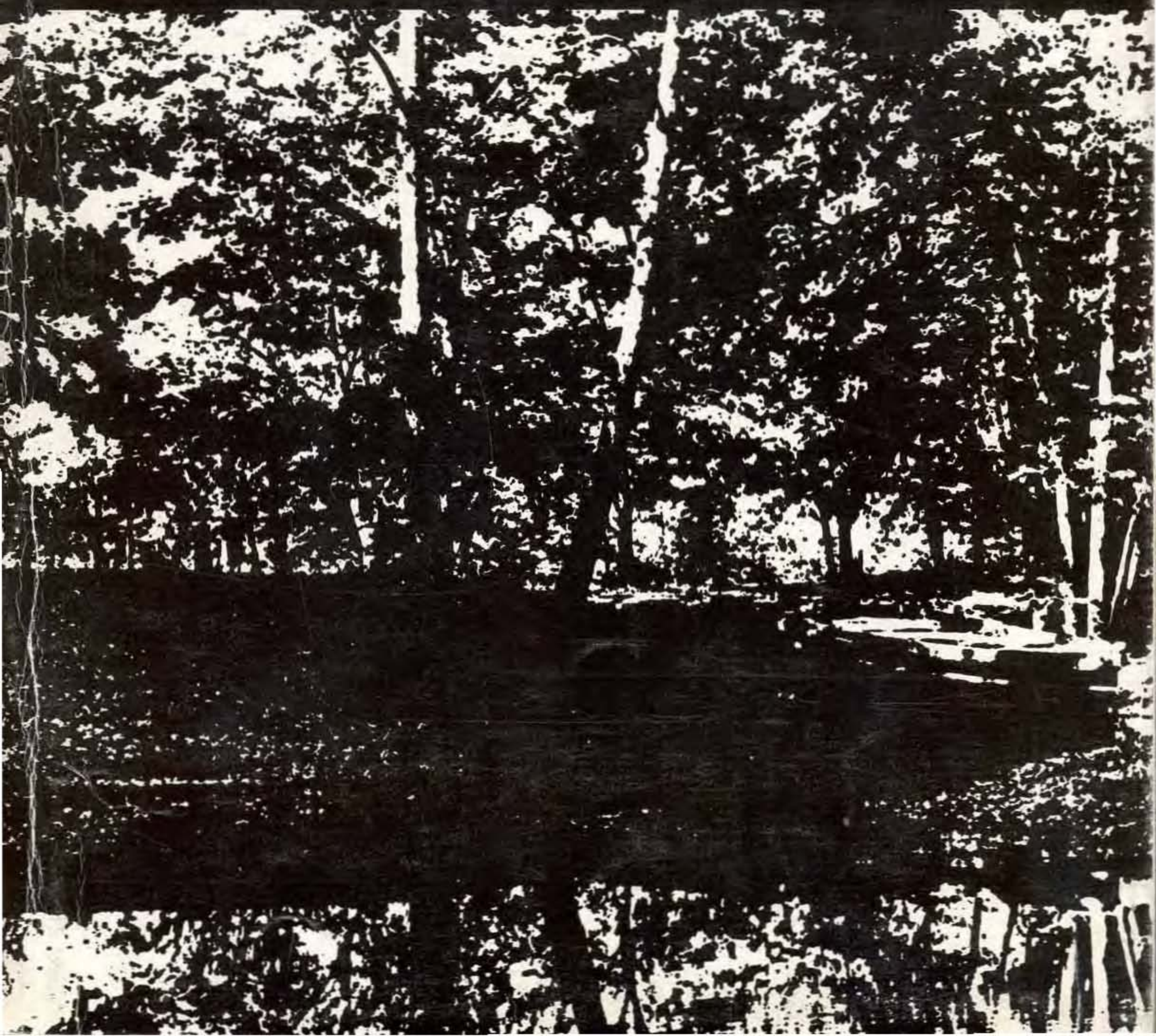
Hydrology of Carbonate Terrane — Niangua, Osage Fork, and Grandglaize Basins, Missouri

by E.J. Harvey, John Skelton, and Don E. Miller



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HYDROLOGY OF CARBONATE TERRANE — NIANGUA, OSAGE FORK, AND GRANDGLAIZE BASINS, MISSOURI

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with a section on

Engineering Geology of
Conns Creek Drainage System

by

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ABSTRACT

A hydrologic study of an area comprising three Missouri Ozark basins (Niangua River, Osage Fork, and Grandglaize Creek) and an analysis of hydrologic methodology for study of carbonate terranes have shown that there are intricate relationships between groundwater and surface water and that these relationships can best be understood by using a number of study methods. None of the methods, however, can be applied independently to describe the hydrologic system.

The study area is underlain by about 1800 ft of Ordovician and Cambrian rocks, largely dolomite, uninterrupted by a consistent confining bed. As a result, vertical percolation of water has enlarged openings along joints and fractures throughout the section, allowing relatively easy passage of water.

An important controlling factor on the hydrology of Ozark basins is the amount and type of structural deformation of the rocks. Faulting and jointing deflect streams, alter streamflows, and direct the underground movement of water.

The measurement of streamflow, in combination with geologic mapping, is one of the most important tools in hydrologic studies of carbonate terranes. Seepage-run data provide excellent information about the magnitude and distribution of low flows within and among stream basins, information that can be related to distribution and direction of faulting and jointing, and development of permeability.

Current and historical groundwater-level data are also essential hydrologic tools in studying carbonate terranes. Well depths, water levels, and yields vary greatly within short distances because of variable development of permeability in the rocks. The classic concept of a water table is approximated in only a few places in the study area; these are in alluvial material along perennial streams such as the Niangua River and Osage Fork.

An effective way to study groundwater-surface-water relationships is to construct basin profiles, using groundwater levels and streamflow data in conjunction with topographic, geologic, and structural information. Such profiles include much of the pertinent data for hydrologic analysis.

Dry Auglaize Creek and Goodwin Hollow in the Grandglaize Creek basin are underlain by the most extensive underground drainage system in the project area. Dye tracing has shown that both are hydraulically connected to the Niangua River, beneath a major divide. Field observations have shown (1) that more storm runoff is diverted to Niangua River by Goodwin Hollow than by Dry Auglaize Creek and (2) that stream reaches and tributaries nearest the Niangua River basin have the largest infiltration capacities.

An engineering geology study in Conns Creek basin was useful in relating a site study to the broader hydrologic relationships of an entire basin. Test drilling showed that the alluvial fill is incapable of transmitting large volumes of water after a rain and that conduits in bedrock are required to carry such flows.

INTRODUCTION

A complex hydrologic system has evolved in the Missouri Ozarks, where crustal movement has occurred often during the geologic past and where more than a thousand feet of soluble rock exist with no continuous confining bed to interrupt the vertical passage of water. Impose upon the system a hundred years or so of artificial development reflecting the increasingly diversified needs of the inhabitants, allow those needs to interact with a hydrologic system that has matured over a few hundred million years, and a complexity results that must be clarified to achieve an understanding useful to the inhabitants in making decisions on how to live in harmony with the natural environment.

The Ozark region of Missouri has many desirable features making it attractive for future intense development. For example, the weather is generally moderate; the area is not densely populated; the perennial streams of the area are clear, cool, and fed by numerous springs; and groundwater supplies are generally unpolluted and have been adequate for most uses.

The prospect of extensive development has caused concern about the future quantity and quality of water resources. A primary reason for concern is that numerous streams and upland areas in the carbonate terrane of the Missouri Ozarks recharge the groundwater system, which is used extensively for water supplies and is the source of the many large springs in the region.

In areas with losing streams, an understanding of the hydrologic system is needed to insure that streams and aquifers are not contaminated. In order for responsible officials to manage water resources wisely, they must have information indicating areas where groundwater pollution could result from accidental spills or unwise location of waste-disposal facilities. For example, a new sewage-treatment plant is currently releasing effluent into a losing reach of Dry Auglaize Creek. Highways, railroads, and pipelines can be scenes of accidents and, thereby, sources of contaminants.

This report contains the results of hydrologic investigations in three basins on the Salem Plateau, about 45 mi northeast of Springfield (fig. 1). The project area included the drainage basins of Niangua River and Grandglaize Creek upstream from Lake of the Ozarks, and Osage Fork, with a combined drainage area of approximately 1500 mi^2.

The natural features of the region are similar in many respects to those of carbonate areas elsewhere in the temperate zone and greatly influence regional hydrology. A number of the streams lose all or part of their flow to underground drainage systems; there are areas of extensive sinkhole development and numerous caves, springs, and seeps.

The decision of the Missouri Department of Natural Resources, Division of Geology and Land Survey, and the U.S. Geological Survey to make this study was prompted by the need to determine the supportive characteristics of the various types of data collection methods and the desire to learn more about the hydrologic system in karst terranes. The three basins chosen for study are considered typical of carbonate basins in the Missouri Ozarks.

PURPOSE AND SCOPE

The primary purpose of this report is to present hydrologic information on the Osage Fork, Niangua River, and Grandglaize Creek basins, with emphasis on distinguishing losing and gaining stream reaches and their relationship to groundwater movement. An important facet of this phase of the study was the definition of the low-flow characteristics of streams in the area in sufficient detail to implement Missouri Clean Water Commission regulations; that is, estimate the 7-day Q_{10} low flow at as many sites as possible. A second purpose is to evaluate methods used in defining gaining and losing streams, and to determine their relation to the flow system, the geology, and the physiography, thus permitting future basin studies of this type to be done more quickly and efficiently.

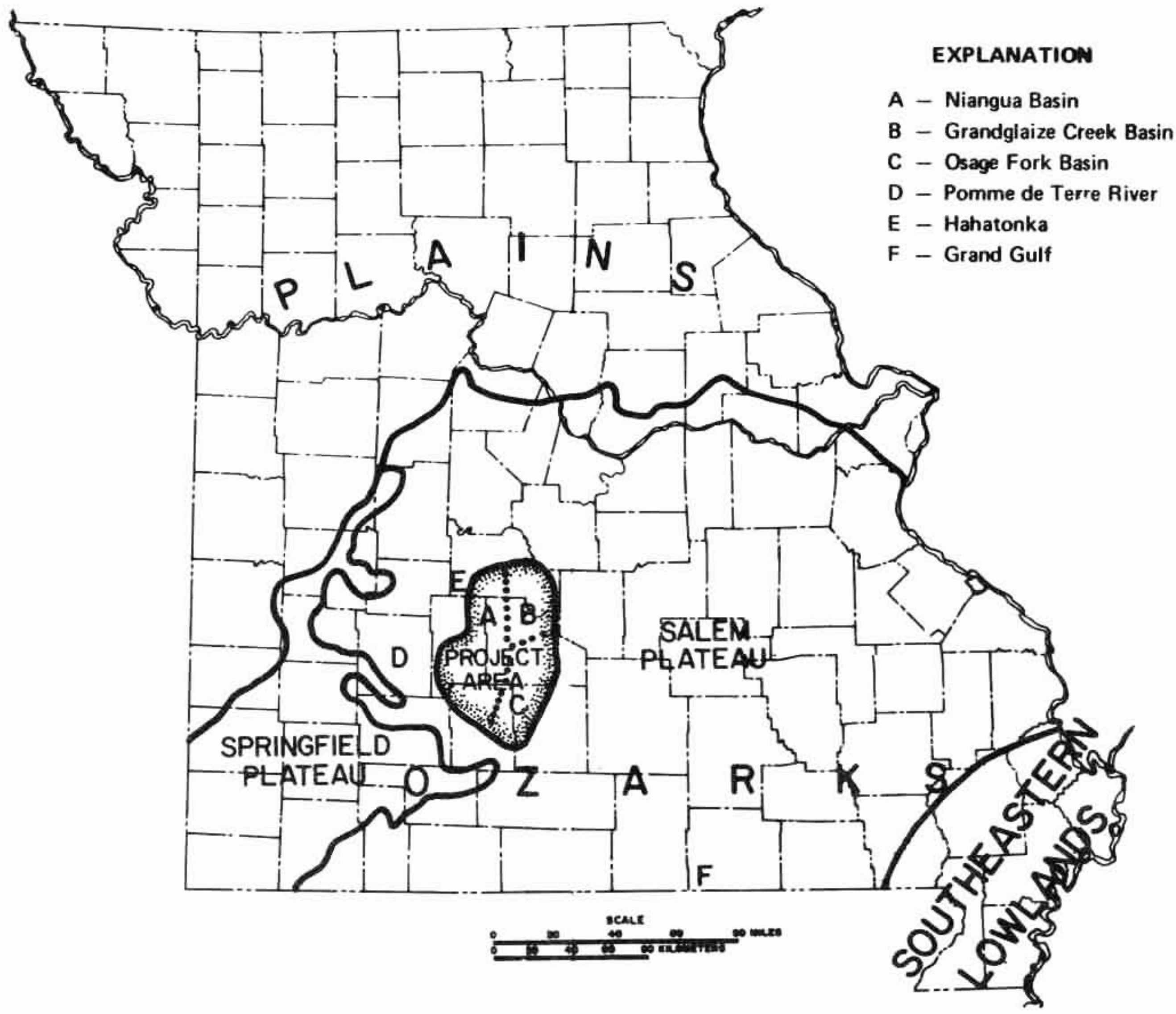


Figure 1. Location of Niangua River, Osage Fork, and Grandglaize Creek basins, and other features mentioned in the report.

DEFINITION OF TERMS AND CONVERSION OF UNITS

1. Conversion of inch-pound units to International System of units:

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.00035	centimeter per second (cm/s)
mile (mi)	1.609	kilometer (km)
acre	4047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	1233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

To convert temperature in degrees Celsius (C) to degrees Fahrenheit (F), use the following equation:
$F = 1.8C + 32$

2. Anticline - An upfold or arch of rock strata in which the beds dip away from the axis.

3. Aquifer - A formation, group of formations, or part of a formation capable of yielding water.

4. Artesian water - Groundwater under sufficient pressure to rise above the level at which the water-bearing strata are reached in a well.

5. Base flow - Sustained or fair-weather flow.

6. Base level of erosion - "An imaginary surface inclining slightly in all its parts toward the lower end of the principal stream draining the area" (Powell, 1875). The level below which a land surface cannot be reduced by the erosional action of running water.

7. Cubic feet per second (ft^3/s) - The unit rate of discharge. One ft^3/s is the rate of discharge of a stream having a cross-sectional area of 1 square foot and an average velocity of 1 foot per second.
$1 \text{ ft}^3/\text{s} = 7.48$ U.S. gallons per second $= 0.646$ million U.S. gallons per day.

8. Dolomitization - The process whereby limestone is partly or completely converted to dolomite by partial or complete replacement of calcium carbonate by magnesium carbonate.

9. Dye tracing - In this report, *dye tracing* refers to the use of rhodamine WT 20-percent dye solution as a tracer in studying underground movement of water and treatment-plant effluent, from loss zones on the surface to points of resurgence.

10. Evapotranspiration - Movement of water into the atmosphere by the combined processes of transpiration from plants and direct evaporation from the soil.

11. Fault - A rock fracture surface or zone along which there has been displacement.

12. Gaining stream or gaining stream reach - A stream that generally increases in flow with an increase in drainage area. Water levels and saturated zones are very shallow in such stream basins.

13. Graben - A crustal block, generally longer than wide, faulted downward relative to the rocks on either side.

14. Hiatus - A "gap" in rock sequence, as shown by absence of geological formations present in other areas, because of nondeposition, or erosion before deposition of succeeding beds.

15. Horst - A crustal block, generally longer than wide, faulted upward relative to the rocks on either side.

16. Hydraulic conductivity - The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area, measured at right angles to the direction of flow.

17. Karst, karstic - A term loosely applied to solution features and phenomena in carbonate terranes. Generally includes a wide range of features, such as caves or other underground drainage, into which surface drainage is diverted by sinkholes, solution-enlarged crevices, and related phenomena.

18. Lithofacies map - A map showing the areal variation in the lithology of a stratigraphic unit.

19. Losing stream or losing stream reach - Stream segment that loses all or part of its flow to underground solution cavities.

20. National Geodetic Vertical Datum of 1929 - A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada. It was formerly called "sea level datum of 1929" or "mean sea level."

21. Permeability - A measure of the relative efficiency with which a porous medium can transmit a liquid under a potential gradient.

22. Potentiometric surface (map) - A surface (map) representing the static head. As related to an aquifer, it is defined by the levels to which water will rise in wells.

23. Reconnaissance mapping - Defined as "a general examination or survey of a region with reference to its main features, usually as a preliminary to a more detailed survey" (Howell, 1957). Geologic maps for this study are more detailed than reconnaissance maps, but not so detailed that they show all minor structural features or exactly define all facies changes in the area. The maps greatly helped the project hydrologists understand the flow system.

24. Recurrence interval - The average interval, in years, between occurrences of a low flow less than that indicated by the data. Recurrence intervals are averages and do not imply regularity of occurrence; for example, an event with recurrence interval of 10 years might occur in consecutive years or might not occur in a 20-year period. An event with a recurrence interval of 10 years has a probability of 0.10 (or a 10-percent chance) of occurring during any given year.

25. Residuum - Material remaining essentially in place after all but the least soluble constituents have been removed by rock weathering and decomposition; also called *regolith.*

26. Seepage run - A series of discharge measurements made at numerous sites along a stream reach, during a short period of time, to identify where gains or losses in flow occur. At each point, measurements of temperature and specific conductance of the water provide supplementary reconnaissance information.

27. Silicification - The introduction of, or replacement by, silica, generally as fine-grained quartz, chalcedony, or opal; it may fill pores and replace existing minerals.

28. Sinkhole - A surface depression, usually without surface outlets, occurring in regions of soluble rock and connecting with subsurface drainage networks. Sinkholes are caused by solution and collapse or subsidence of the underlying formation(s).

29. Specific capacity - The rate of discharge of water from a well, divided by the drawdown of water level or head in it. For example, if a well yields 200 gpm (gallons per minute), with a drawdown of 50 ft, its specific capacity is 200/50, or 4 gpm per foot of drawdown.

30. Standard deviation - The square root of the arithmetic average of the squares of the deviations from the mean.

31. Stromatolitic reef - A structure made up of stromatolites, laminated, variously shaped organosedimentary structures (stratiform to columnar, nodular, or subspherical) produced by micro-organisms, predominantly (at least in the case of modern forms) blue-green algae (Cyanophyta).

32. Syncline - A fold in rocks in which the strata dip inward from both sides toward the axis.

33. Transmissivity - The rate at which water of a prevailing kinematic viscosity is transmitted through a unit width of the aquifer, under a unit hydraulic gradient.

34. Water table - The upper surface of a zone of saturation except where that surface is determined by impermeable overlying rock.

35. Wrench fault - A nearly vertical strike-slip fault in which the net slip is partially in the direction of the fault strike.

36. X-day Q_n - The average minimum flow for X consecutive days, with a recurrence interval of n years. For example, the 7-day Q_{10} is the 7-day average minimum flow, with a recurrence interval of 10 years.

37. Zone of saturation - The crustal zone in which all voids are water filled.

WELL LOCATION SYSTEM

In this report, well locations are referred to in accordance with the system of the Bureau of Land Management Survey, using the following order: township, range, section, quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). The subdivision of a section is designated a, b, c, and d in counter-clockwise direction, beginning in the northeast quarter. If several wells are in a 10-acre tract, they are numbered serially after the above letters, and in the order inventoried.

METHODOLOGY AND TYPES OF DATA COLLECTED

One purpose of the project was to use a number of methods of investigation and determine to what extent results from each method supported the others.

Methodology and types of data collected included the following:

1. Water-level measurements, including construction of a potentiometric map and groundwater profiles.
2. Streamflow measurements, including seepage runs on all major streams and on most of the tributaries.
3. Geologic mapping.
4. Identification of plant assemblages at all streamflow measuring sites.

5. Stream-profile analysis to define relationships between streamflow, geology, and stream gradient.
6. Engineering geology study of soil, shallow bedrock, structural features, and streamflow in Conns Creek drainage basin, a losing tributary of Wet Glaize Creek.
7. Dye tracing to determine subsurface movement of groundwater from points of loss to points of resurgence.
8. Soil temperature studies in the flood plains of streams with shallow (gaining stream) and deep (losing stream) water tables.
9. Analysis of drainage density and its relation to low-flow frequency.
10. Analysis of physiographic development and its relation to runoff and surface geology.
11. A study of well yields from the several aquifers to determine relations between yield and topographic situation, producing formation, and location within a gaining- or losing-stream valley.
12. Analysis of water-quality data collected on wells, streams, and springs. Potential usefulness of such data in basin-type studies was evaluated.
13. An analysis of the practicality of remote sensing and thermal-imagery data for these studies.

DESCRIPTION OF THE AREA

CLIMATE

The project area has a humid continental climate, with changeable weather and extremes of temperature and precipitation in some years. The average temperature (all averages based on 1941-70 data at Lebanon) is 56.1°F. The average for July, the hottest month, is 77.2°F and for January, the coldest month, 33.4°F. The average annual precipitation is 40.4 in. Usually, the maximum monthly precipitation occurs in April (4.09 in.); the minimum, in January (1.78 in.).

During the current study, the variability in the climate was evident, with some significant departures from the 1941-70 averages at Lebanon. The following table summarizes abnormal temperature and precipitation during the period of data collection for this project:

Temperature and precipitation departures from 1941-70 averages at Lebanon, Missouri

(Data from National Oceanic and Atmospheric Administration)

Year	Temperature departure from average (F)	Precipitation departure from average (in.)
1974	+0.2	+3.3
1975	+0.5	+2.3
1976	-0.5	-12.7
1977 (January – September)	+6.5	+9.6

PHYSIOGRAPHY AND LAND USE

The topography of the project area is shown in figure 2. The land surface is gently rolling in the central and southern parts, where much of the land is cultivated (fig. 3). Relief in the area around Lebanon is generally less than 100 ft, and even along the streams draining from the Marshfield-Lebanon divide, relief is low.

Along the main stems of the Osage Fork, Niangua River, and Grandglaize Creek, relief is greater, especially along the lower half of the Niangua River in the northern part of the area. Little of the gently rolling land so prominent near Lebanon remains, and ridges between tributaries are long and narrow. Slopes along the lower Niangua River are mostly wooded (fig. 3 and plate 1). Dolomite bluffs are 200 ft high in some reaches, and 100 to 150 ft high along Osage Fork and Wet Glaize Creek.

Total relief along the Niangua River and Osage Fork ranges from 100 to 300 ft. The character of the relief is different, however, as shown by the distribution of woods and cleared land. The amount of woodland remaining is

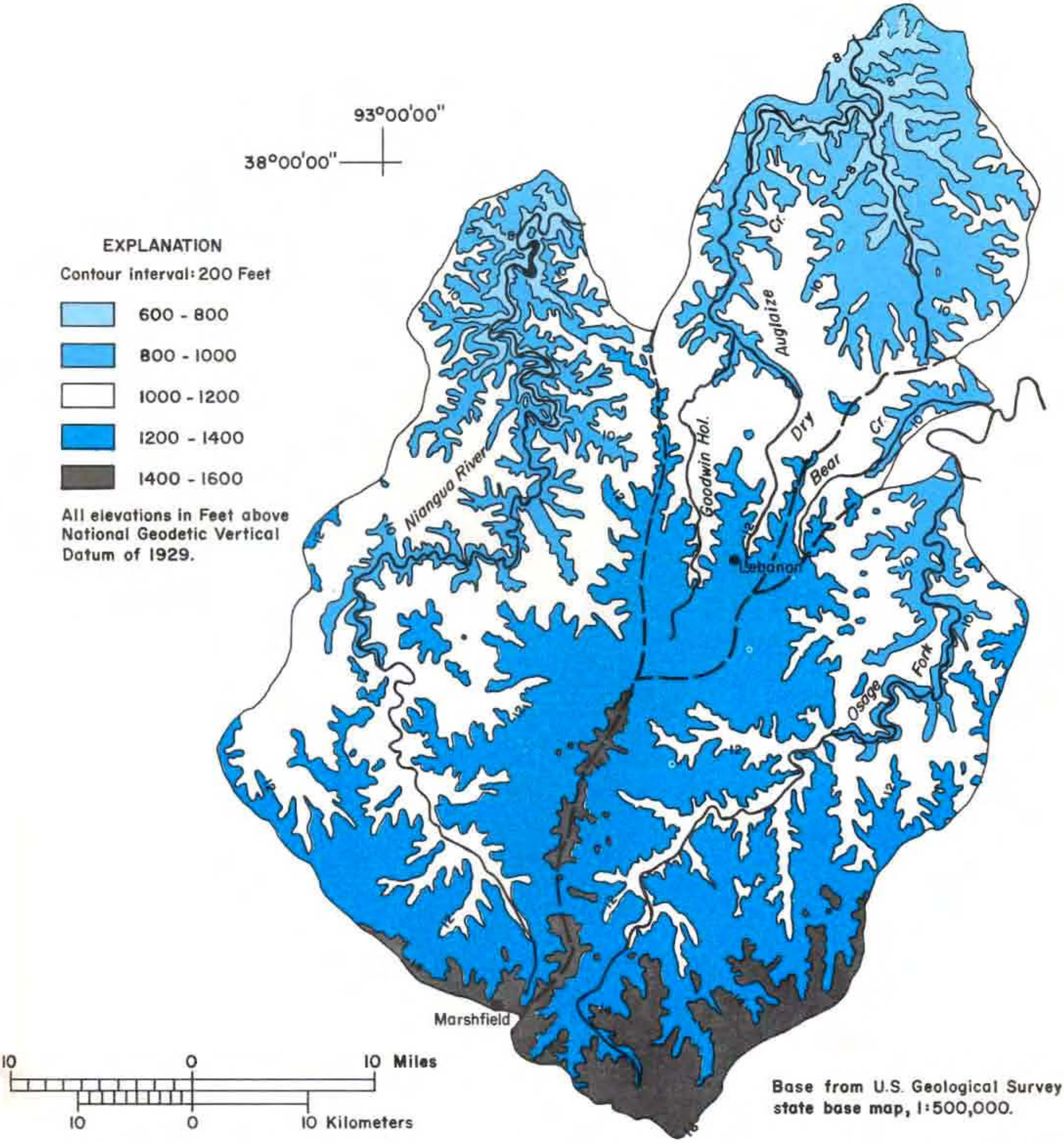


Figure 2. Topography of the Niangua River, Osage Fork, and Grandglaize Creek basins.

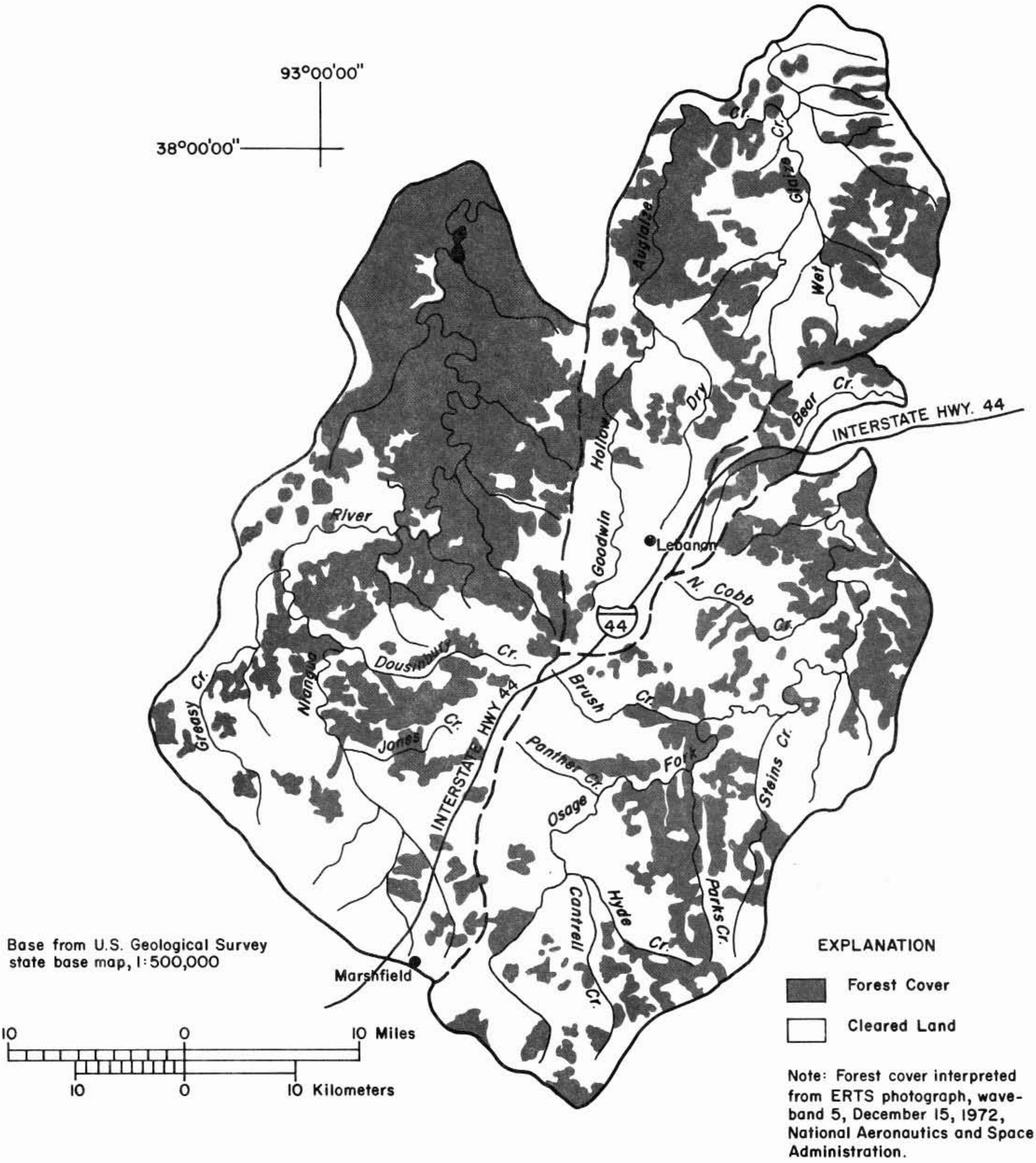
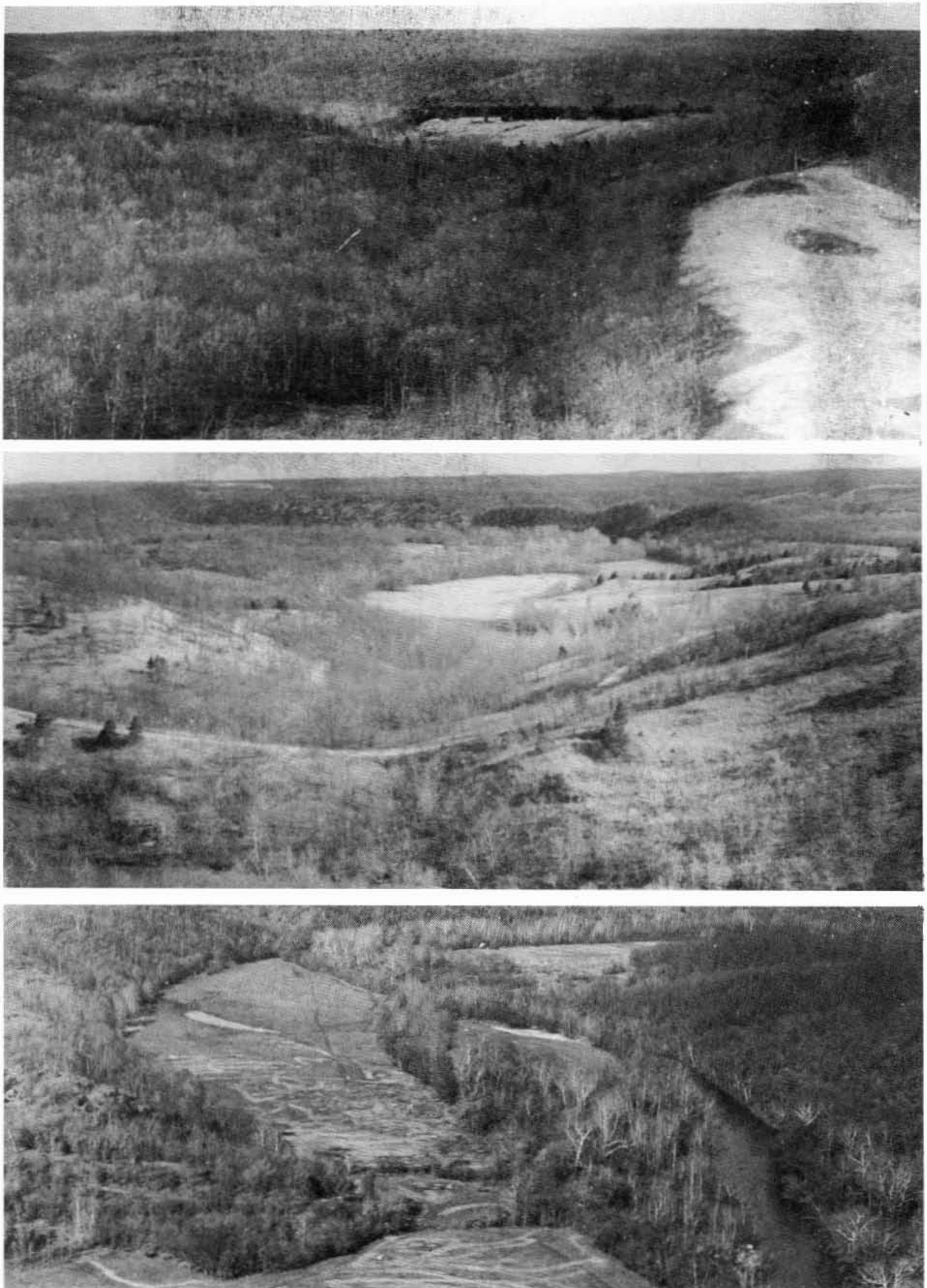


Figure 3. Areal distribution of forest cover.



A

B

C

Plate 1. Wooded topography along the lower Niangua River, showing the long, narrow ridges between tributaries. Note accordance of topography in 1A and 1B. The broad, flat feature shown in the center of 1C is the valley floor of the Niangua River near Sweet Blue Spring in T. 36 N., R. 17 W. Photographs by James E. Vandike.

determined by the relief (plate 2). In areas of high relief, cleared land is mainly in the valleys; in areas of moderate to low relief, it is on the divides as well as in the valleys.

In recent years, cattle grazing has greatly increased (Missouri Crop and Livestock Reporting Service, 1976). Between 1941 and 1970, a moderate yearly increase in cattle grazing

A

B

Plate 2. Distribution of woodland is determined by relief. In areas of high relief, such as the view northward in Dry Auglaize Creek basin, shown in 2A, cleared land is mainly in the valleys. View 2B shows clearing of moderate slopes in the area of an abandoned meander loop along Dry Auglaize Creek. Photographs by James E. Vandike.

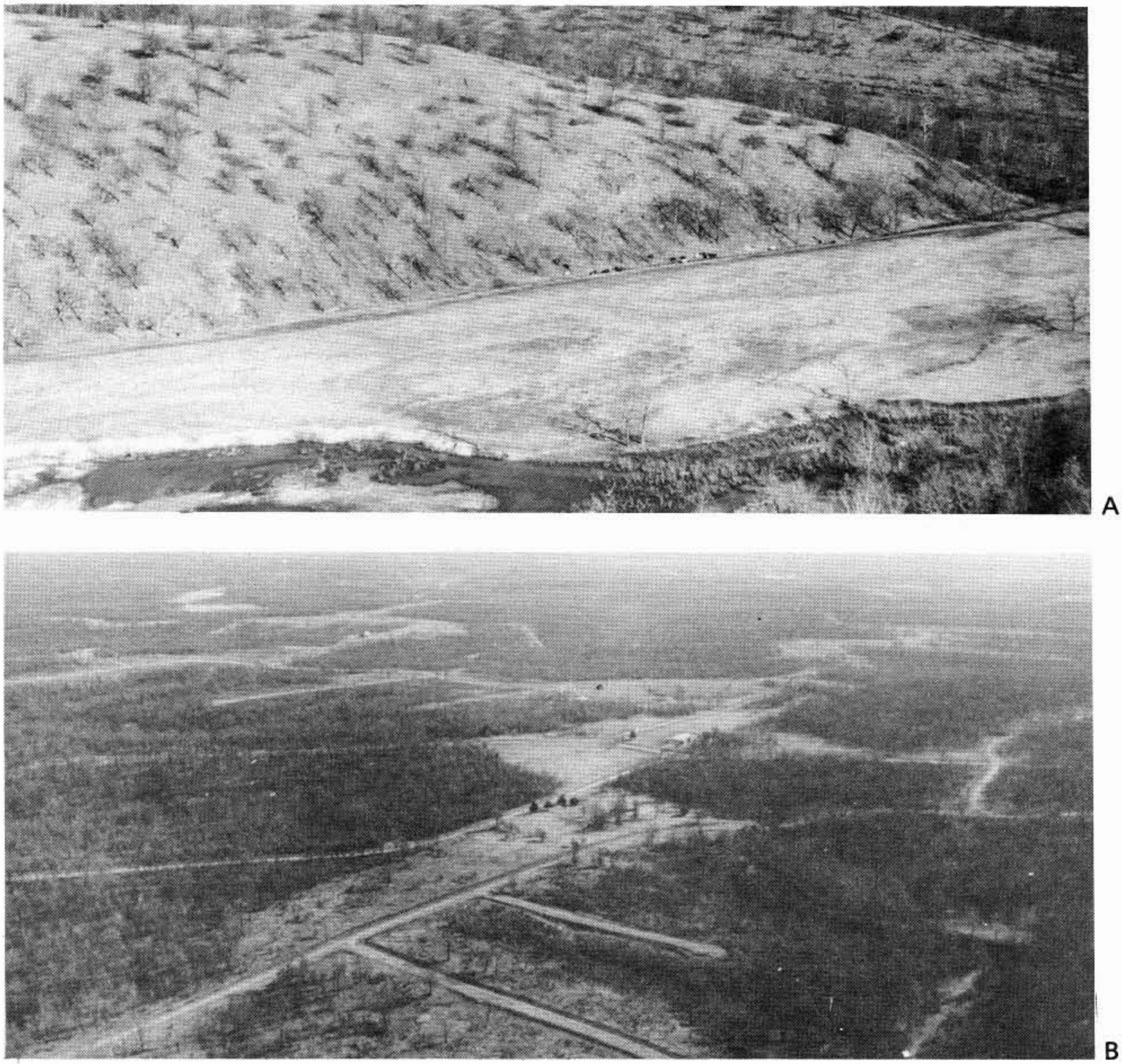


Plate 3. Land clearing on slopes, valleys, and upland ridges, resulting from increased cattle grazing in the area, is shown in 3A and 3B. These are views of land clearing in the Jakes Creek drainage, in sec. 34, T. 36 N., R. 18 W., Dallas County. Photographs by James E. Vandike.

occurred in all of the study area. In 1975 an increase of 45 percent over 1970 surpassed the average increase during previous 5-year periods. Concurrent with this increase in cattle population, much land has been cleared, slopes as well as uplands (plate 3).

Although there has been considerable clearing, some tracts have reverted to scrub timber growth. Cleared land and timbered land would tend to counteract each other in their gross effect on precipitation as it becomes groundwater recharge and base flow, surface runoff,

A


Plate 4. Modified dendritic drainage patterns in the study area reflect strong structural control. The 90-degree bends shown in 4A and 4B, along the Osage Fork of the Gasconade River, in T. 33 N., R. 15 W., are examples of such control. Photographs by James E. Vandike.

or vapor. Figure 3 depicts forest cover in 1972; no doubt the future distribution will differ in detail.

The hydrologic effect of small changes in land use is difficult or perhaps even impossible to measure, but a substantial conversion from woods to pasture might allow a comparison of hydrologic conditions before and after the change. However, records collected since significant conversion to pastureland are few and do not indicate significant effects on hydrology.

The modified dendritic drainage pattern in the area reflects the strong influence of fault and joint patterns. Many 90-degree bends in main stem, tributaries, and divides occur throughout the area (plate 4); many short reaches of streams have straight northwest, north, and northeast segments that suggest structural control. Solution along fracture systems was important in the position of valleys and divides. For example, the ridge that divides the Niangua and Osage Fork, extending from Marshfield to Lebanon, is offset several miles to the northwest in the area where a northwest-trending fault zone crosses the upper ends of the two basins (compare figs. 2 and 4, in pocket). The East Fork of the Niangua is extending headward into the Osage Fork basin, offsetting the divide.

B

Plate 4 (continued)

Other topographic and hydrologic features reflect structural control:

1. The southwestern boundary of the project area forms an unusually straight line; the south corner, a 90-degree angle.
2. The upper Niangua parallels a northwest-trending fault zone; a pronounced change in the gradient of Osage Fork occurs at an altitude of 1220 ft, in approximate alignment with the fault zone; and four springs at the Dallas-Webster County line, near the intersection of this fault and a northeast-trending fault, markedly increase the flow of the Niangua River.
3. Dry Auglaize Creek flows approximately 7 mi northwest in a graben (fig. 4, in pocket), a structurally controlled reach containing the junction of Goodwin Hollow and Dry Auglaize. After the junction, Dry Auglaize Creek leaves the graben, flows north approximately 18 mi, and abruptly turns east to the junction with Wet Glaize Creek.
4. The Niangua River abruptly changes from a northwest to an easterly course just downstream from the mouth of Greasy Creek (fig. 4, in pocket), continuing thus about 8 mi before flowing north again.

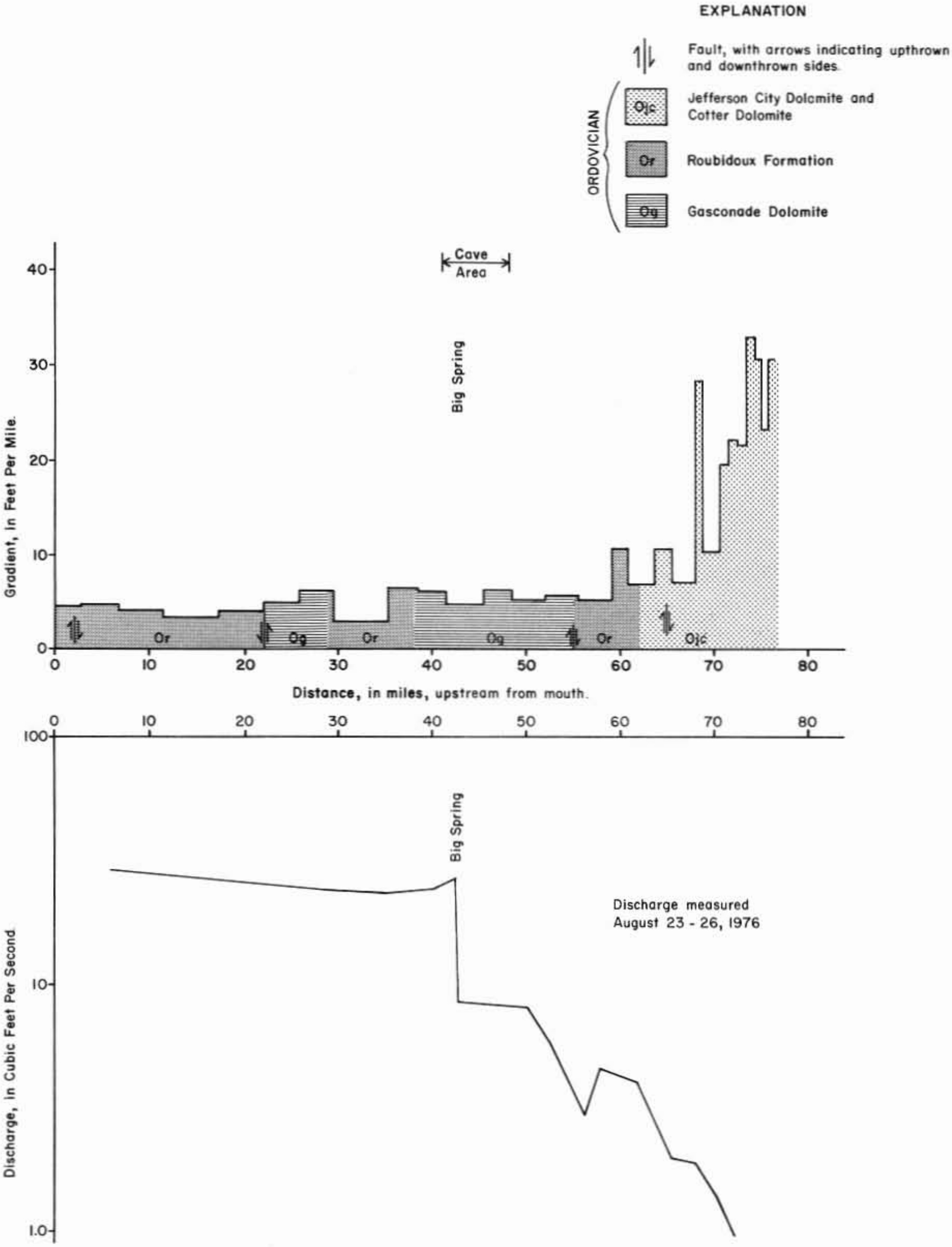


Figure 5. Stream gradient and discharge, Osage Fork.

5. Probably the outstanding example of structural control on topography and hydrology in the three-basin area is illustrated by the relationship of the three basins to each other. The Niangua River reaches a common divide with the Osage Fork flowing east and the James River to the south, and the Grandglaize Creek basin is cut off (fig. 2). The ridge separating the Wet Glaize from the Dry Auglaize, paralleling the graben in which the Dry Auglaize flows, and forming a part of the Camden-Laclede County line helped restrain headward development of the Grandglaize basin. As a result, assuming the Grandglaize and Niangua began their southward basin development more or less simultaneously before the last Ozark uplift (Bretz, 1965), the Grandglaize system, which includes the Wet Glaize, Dry Auglaize, and Goodwin Hollow, did not advance headward (southward) as rapidly as the Niangua River. As shown in subsequent sections of the report, only the Wet Glaize basin presently (1978) contributes continuous flow to Grandglaize Creek, and most runoff from Dry Auglaize Creek basin is diverted westward to the Niangua basin.

Profiles of Streams

The main streams, such as Osage Fork and the Niangua River, have moderately smooth, concave profiles through the downstream 75 percent of their reaches (figs. 5 and 6). The average gradients of Osage Fork and Niangua River are nearly the same: 3.6 and 3.9 ft/mi, respectively. However, the rate of descent of the Niangua is greater in the upper reaches than that of the Osage Fork, indicating greater cutting power along the upper part of the Niangua River.

In short reaches of the streams (figs. 5 and 6), there are many irregularities that may reflect lithology or stratigraphy; others are due to faults that may abut strong and weak beds. Still others result from substantial inflows or losses of water or combinations thereof. Since running water is mainly responsible for shaping valley profiles and for headward extension of valleys, quantity and duration of flow are important factors; nevertheless, lithology and fracturing of rock are overriding influences on detailed sculpturing of profiles.

The contrast in gradients in the upper reaches of the Osage Fork (fig. 5) are the most pronounced: 28.6 ft/mi and 7.4 ft/mi in adjacent reaches. The steepened reach is near the southeast extension of a Niangua basin fault (fig. 4, in pocket) paralleling the mapped fault crossing the Osage Fork about 3 mi downstream. Because several northwest-trending faults cross the area in this vicinity, variations in lithology between adjacent fault blocks could cause these gradient changes. No marked increase in flow occurs here.

Some of the best indications of a possible relation between spring inflow and gradient are evident in comparing the profiles of three tributaries of the Niangua River and Osage Fork (fig. 7). Mill Creek, a spring-fed perennial stream, changes gradient markedly at springs about 3 mi upstream from its mouth. The profile of Mountain Creek, a stream generally dry throughout its length, is nearly featureless. North Cobb Creek, an Osage Fork tributary, perennial in its lower reaches, has a normal concave profile to within 7 mi of its mouth. In downstream reaches the gradient steepens as perennial flow begins, and continues on a new concave profile to the mouth.

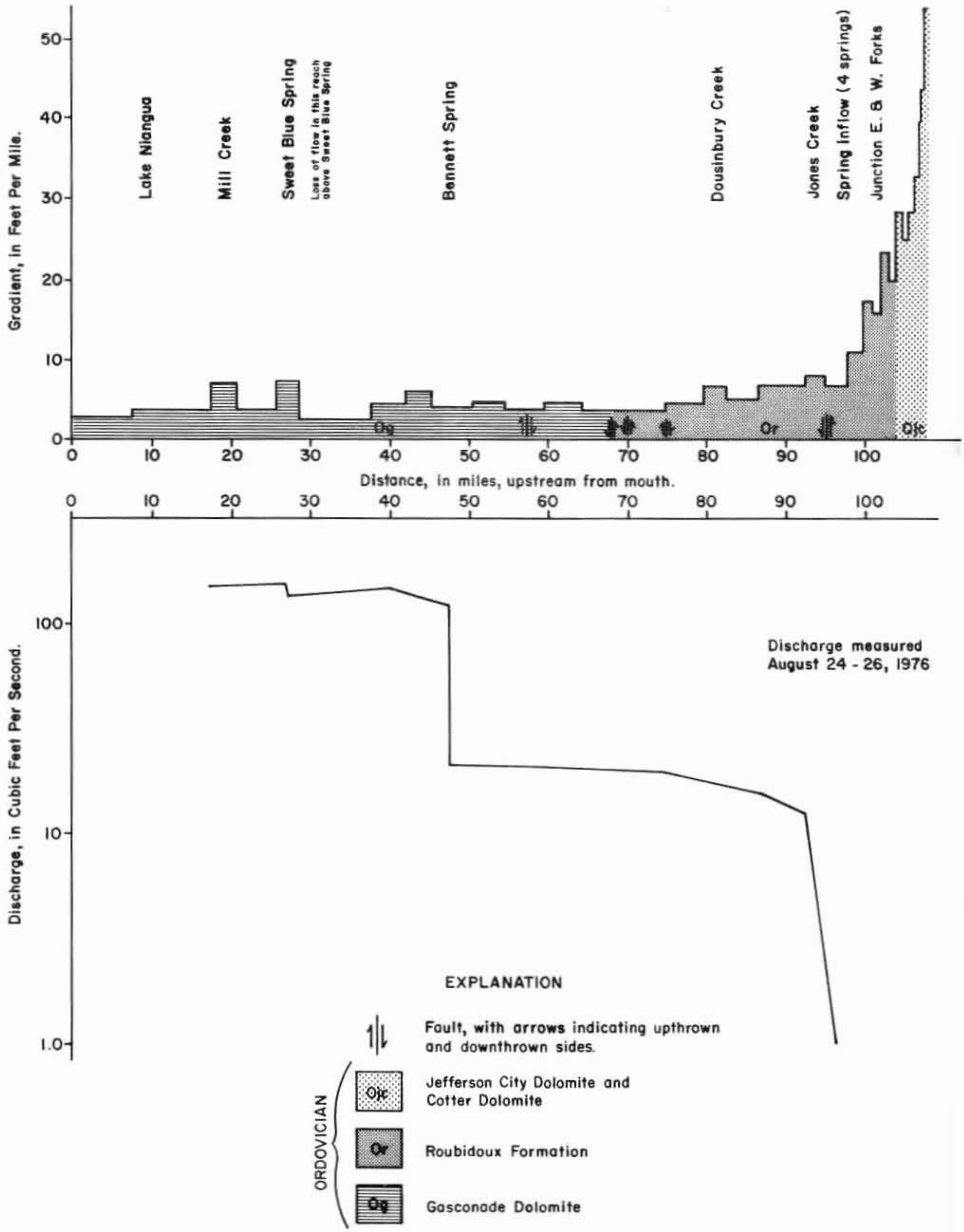


Figure 6. Stream gradient and discharge, Niangua River.

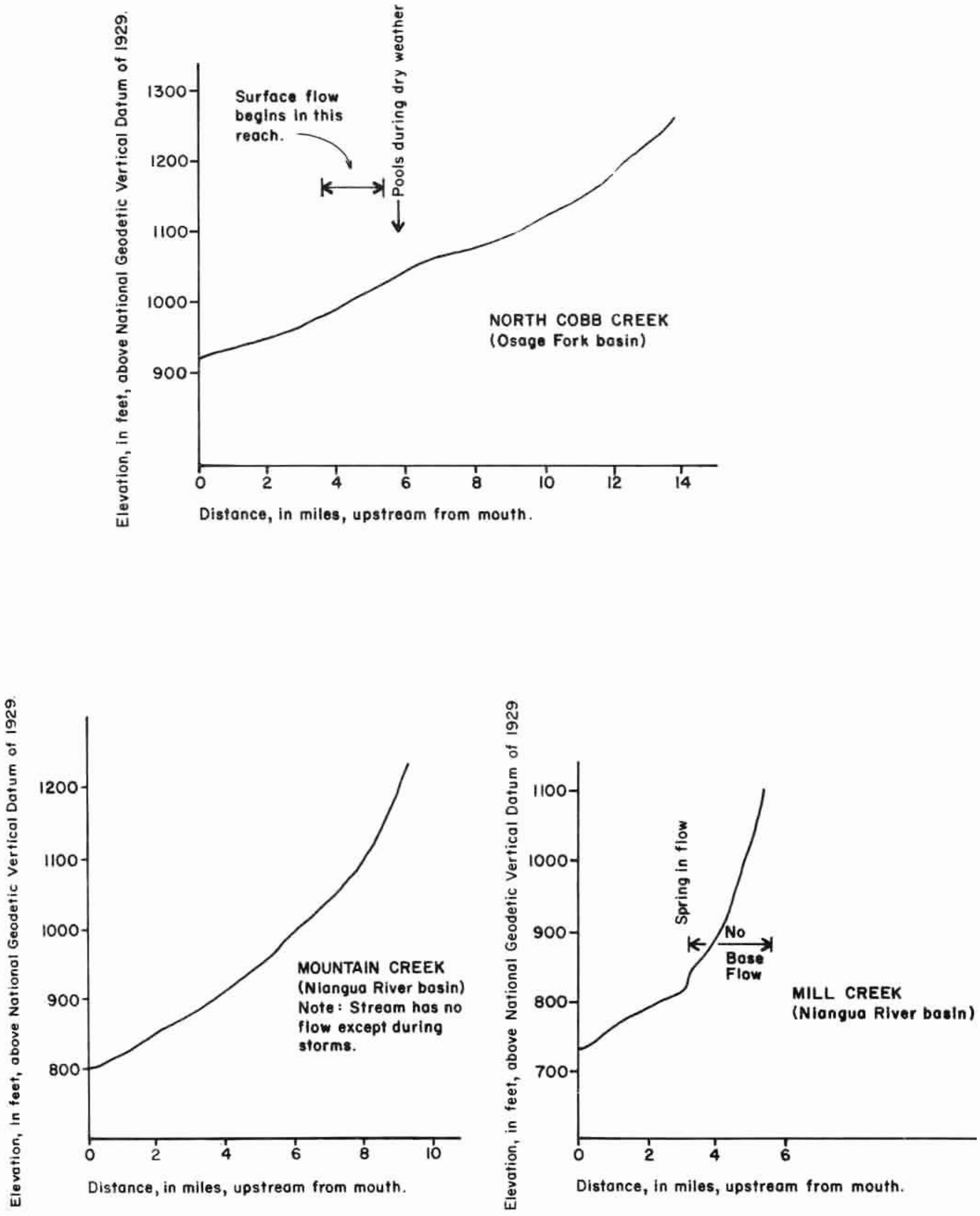


Figure 7. Stream profiles of typical valleys in the Niangua River and Osage Fork basins.

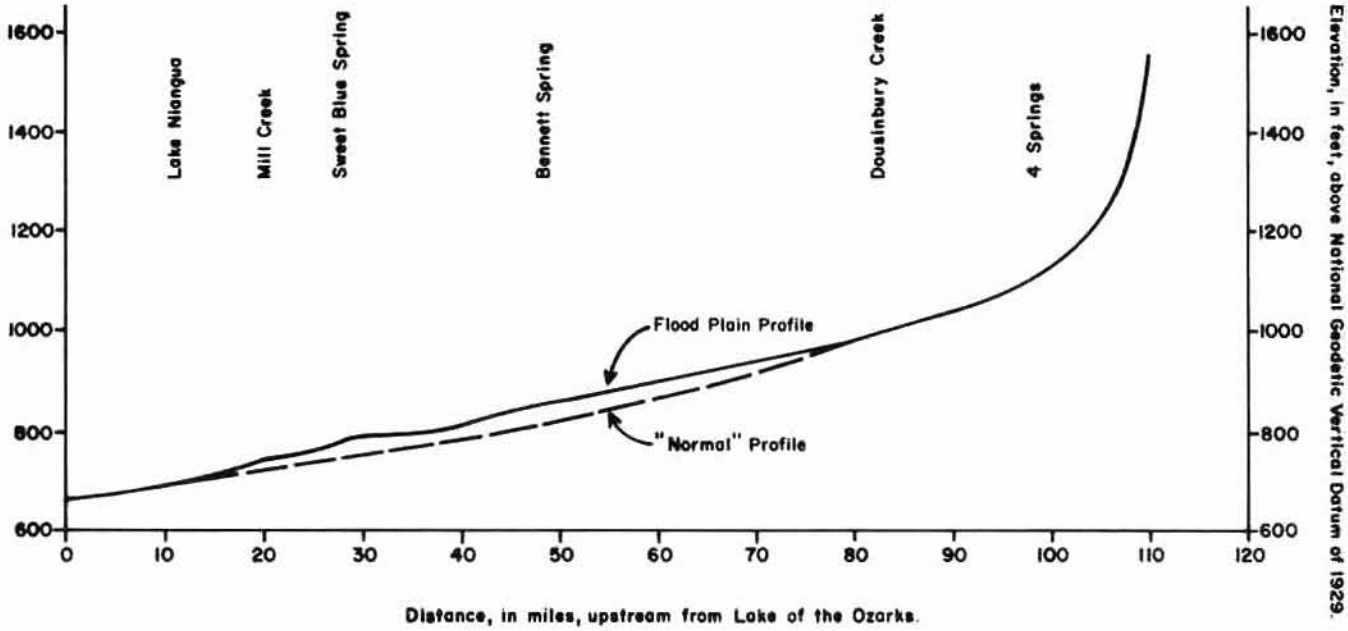


Figure 8. Stream profile of the Niangua River.

A long, subtle flattening in the slope of Niangua River begins near the mouth of Dousinbury Creek, extends to Bennett Spring (fig. 8), and includes that reach of the Niangua River that changes direction abruptly from a northwest to an easterly course (fig. 4, in pocket). Where the flow increase of the stream is not sufficient to keep it at grade (the dashed line in fig. 8), the grade flattens. In this reach of the Niangua River, tributaries contribute very little water, and there is little increase in discharge in the Niangua itself. The profile begins to steepen in the vicinity of Bennett Spring, reaching its projected normal profile in the vicinity of Lake Niangua. Not until Bennett Spring Creek, Sweet Blue Spring, and other springs and tributaries in the downstream reach add their discharges does the gradient steepen sufficiently so that there is a return to what may be considered a "normal" gradient and profile.

In many cases, marked changes in gradient in short reaches along the main streams may be logically attributed to differences in lithology or to structure, whereas the longer, more gradual changes are due to discharge. Along the tributaries, either flow, lithology, structure, or a combination of these factors may cause changes in gradient.

Development of Karst Features

Sinkhole topography is prominent on the level areas extending along the divides radiating from Lebanon (fig. 9). The broad area underlain by the Roubidoux Formation lies between 1200 and 1400 ft above the National Geodetic Vertical Datum (NGVD) of 1929, and contains most of the sinkholes (compare figures 2, 4 (in pocket), and 9). In this karst recharge area, dry or intermittent streams are the rule and groundwater levels are deep. Between 1000 and

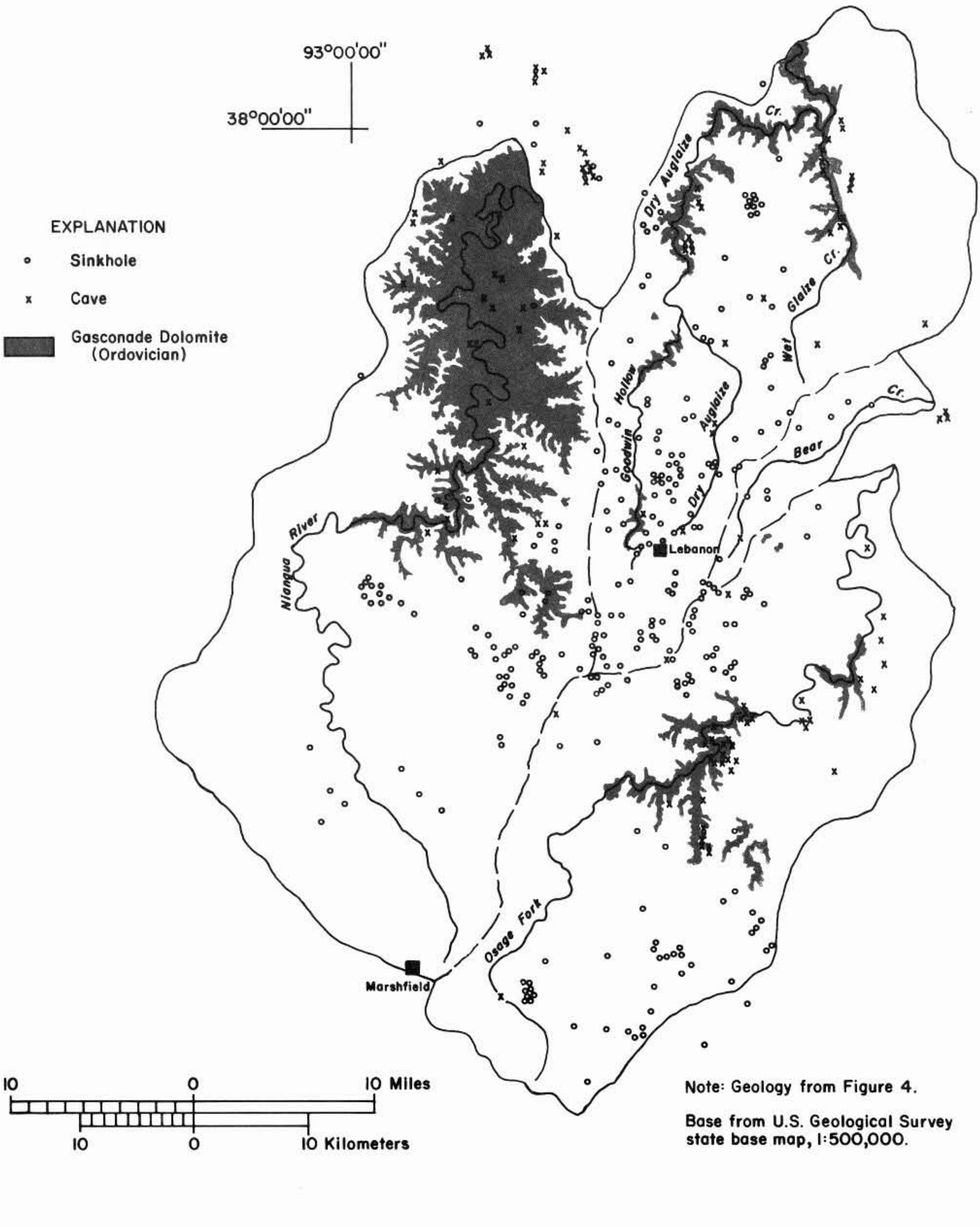


Figure 9. Areal distribution of caves and sinkholes.

1200 ft, there are fewer sinks in the Roubidoux, and as relief increases, they become even less numerous. Few lie below 1000 ft or in the Gasconade Dolomite, the formation generally cropping out at lower elevations.

Plate 5.
Aerial view of Grand Gulf, Oregon County, showing an advanced stage of karst development in Ozark carbonate rocks. This sinkhole is approximately 200 ft deep and about one mile long. Drainage from Grand Gulf is to Mammoth Spring, Arkansas, several miles to the southeast. Photograph by Jerry Vineyard.

Sinks in the area are of two types: (1) shallow, broad, and open, and (2) deep and chimneylike. The shallow ones are caused by steady subsidence, whereas the chimneylike sinks are due to sudden collapse. A few have been observed in the losing reaches of stream valleys where groundwater levels are 50 to 75 ft below flood plain. Although sinks are common in the project area, their presence does not preclude a well-developed surface-drainage network. Stream density, however, is less where sinks are common.

Stages in development of karst topography in the project area can best be appraised outside it. In Grand Gulf, Oregon County (fig. 1), the most advanced stage of development is a collapsed valley, a chasm approximately 200 ft deep and a mile long (plate 5). In the upland bordering Grand Gulf, it would probably be necessary to drill wells more than 200 ft deep, as the water level would probably be below that depth. Along Logan Creek in Reynolds County (fig. 1), an infrequently flowing intermittent stream, groundwater levels are as much as 250 ft below flood plain level. Sinkholes, representing an intermediate stage of karst development, occur on the flood plain along the valley. Just north of Hahatonka spring is a large sinkhole, spanned at its northeast end by the natural bridge illustrated on plate 10, that probably has some connection to the spring system (plate 6).

In the project area, in a less advanced stage, Goodwin Hollow has water levels 70 to 100 ft below the flood plain, and the stream seldom flows (plate 7). In each case (Grand Gulf, Logan Creek, and Goodwin Hollow), the surface stream has been pirated, and each feature represents a different stage in geomorphic development by corrosional work of underground water replacing much of the abrasive work of

A

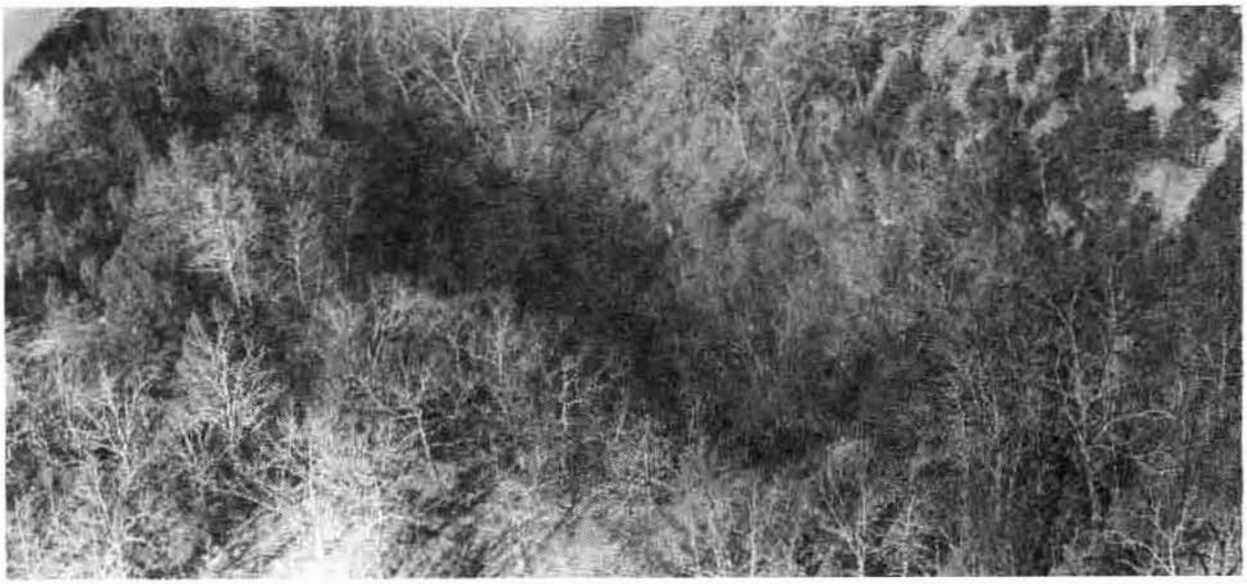


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Plate 6. Aerial views of a large sinkhole northeast of Hahatonka Spring, in sec. 2, T. 37 N., R. 17 W., that probably has some connection to the spring system. Photographs by James E. Vandike.

surface streamflow. As subsurface pirating encroaches from the Niangua River on the west, Goodwin Hollow may eventually show more of the characteristics of Grand Gulf, and Dry Auglaize Creek will assume more of the topographic character of Goodwin Hollow.

Sinkholes and caves are surface and subsurface manifestations of underground drainage. Both may have readily

A

B

Plate 7. Karstic development, less advanced than Grand Gulf, in Goodwin Hollow. 7A is an aerial view upstream in the headwaters, showing classic losing stream characteristics. 7B, taken from a bridge on U.S. Highway 5, sec. 27, T. 36 N., R. 16 W., during a heavy rain, shows water moving into the subsurface and marking the farthest advance of surface-water flow during a single storm event. Photographs by James E. Vandike.

accessible openings into the underground system at the land surface or the openings may be completely hidden beneath the landscape (plate 8).

Much has been written about the role of caves in a karst drainage system. Stringfield (1969) lists some of the investigators who have hypothesized on whether development of caves and enlargement of fractures have occurred above or below the saturated zone. Following is a tabulation of their opinions on the subject:

Cavern development in relation to the saturated zone

Investigator	Below	Above	Near	Remarks
Grund (1963)	X	–	–	
Matson (1909)	–	X	–	
Meinzer (1923)	–	X	–	Uplift
Swinnerton (1929)	–	–	X	
Davis (1930)	X	–	–	Two-cycle; uplift
Piper (1932)	–	–	X	
Gardner (1935)	X	X	–	
Theis (1936)	–	–	X	
Malott (1938)	–	X	–	
Moneymaker (1941)	X	–	–	
Thornbury (1954)	X	–	–	Caves are giant nodes
Bretz (1956)	X	–	–	Three cycle; uplift and filling
Thrailkill (1968)	–	?	?	Caves and sinks only indirectly related
Stringfield (1969)	X	–	–	

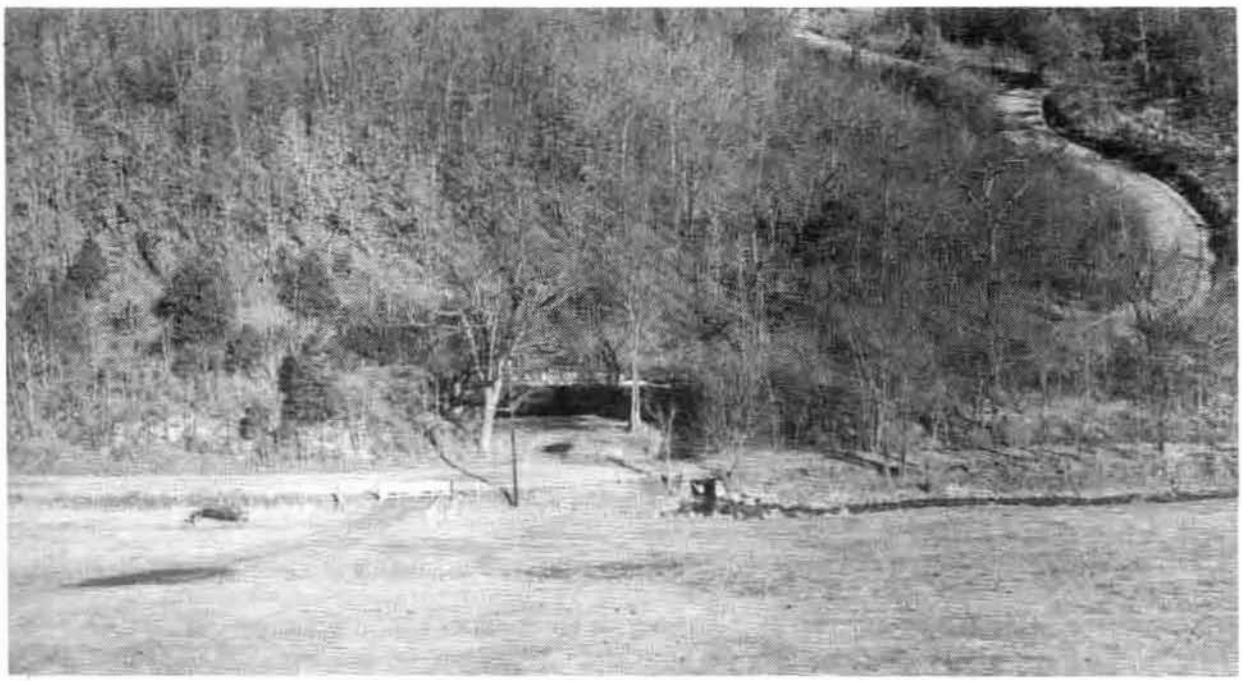


Plate 8. Aerial view of Carroll Cave, sec. 20, T. 37 N., R. 14 W., Camden County. This cave, one of many in the study area, is one of the more spectacular karst features familiar to the public. Only a small fraction of subsurface open spaces resulting from karst development forms large openings such as caves. Photograph by James E. Vandike.

It is apparent there are considerable differences in interpretation, influenced in each case, perhaps, by the part of the world where studies were conducted.

The following outline presents our interpretation of the development of the Niangua River and Dry Auglaize Creek basins:

1. Consequent streams initially. Differential headwater lengthening of streams, the Niangua lengthening more rapidly than Dry Auglaize Creek.
2. Fractures allow penetration of water below the surface mantle. Movement of water and opportunity to descend depend on development of a discharge area. Early solution rapid but selective in zone of aeration; slower but more widespread and more continuous in the saturated zone. With increase in head difference between contributing area and receiving area, movement becomes more rapid, and there is increasing solution near or above the zone of saturation as greater volumes of water are lost by the higher stream. It would seem, therefore, that there must be solution both below and above the saturated zone, but initially more below than above.
3. Faulting, jointing, etc., must influence direction of discharge. Assuming the Niangua River and Dry Auglaize Creek began their headward erosion contemporaneously on an emerged or rejuvenated land surface, many factors such as lithology of the rock units, intensity of fracturing, and differential uplift determined why one valley became a receiving area, and another, a contributing area. In this case, the Niangua River became the receiving area and Dry Auglaize Creek, the contributing area.

GEOLOGIC SETTING

Stratigraphy

The project area is underlain by as much as 1800 ft of Ordovician and Cambrian rocks, largely dolomite. Table 1 lists the formations in the project area and describes their lithologic and hydrologic characteristics.

The stratigraphic section that includes the principal aquifers through the Potosi Dolomite is uninterrupted by a consistent confining bed. As a result, vertical circulation of water has enlarged openings along joints and fractures, allowing freer passage of water from the surface through the Potosi Dolomite.

Pleistocene and Recent alluvial, colluvial, and residual deposits cover bedrock in the valleys and uplands. Except along the river bluffs, exposures of bedrock are discontinuous over much of the area.

The section can be divided into two parts. One comprises the upper 1000 ft or so containing the important aquifers of this study, including the formations down to and including the Potosi Dolomite; the other, those formations between the Derby-Doerun Dolomite and the Precambrian igneous and metamorphic rocks.

Much of the section below the Derby-Doerun Dolomite contains siliceous material largely deposited in a deltaic environment. Those deposits above the Derby-Doerun, which constitute the major part of the section containing the important aquifers, were mainly formed in a shallow carbonate platform environment to which only small quantities of detrital materials were supplied; hence, carbonates are the principal rock

TABLE 1

Stratigraphic column showing generalized lithology and hydrologic characteristics

System	Group, formation, member	Thickness	Lithologic description	Hydrologic characteristics
Quaternary	Alluvium, colluvium, and upland residuum	0-40	Unconsolidated sands, silts, and clay with angular to rounded chert fragments. Soil profiles usually contain a fragipan zone.	Due to large fraction of fine-grained material, these deposits usually have poor water-bearing characteristics.
Mississippian	Burlington-Keokuk, Northview, Compton fms. undivided	0-150(?)	Cherty limestone, siltstone, and thin-bedded crinoidal limestone.	Mississippian sedimentary rocks have limited areal extent; not important as an aquifer in study area.
Ordovician	Cotter Dolomite	0-205	Relatively noncherty, argillaceous, thin- to medium-bedded dolomite. Similar to and locally not distinguishable from underlying Jefferson City Dolomite.	Horizontal permeability of these units appears to be quite low. Yields of wells finished in Cotter-Jefferson City interval are 2-35 gpm, the average being approximately 7 gpm. Observation-well data indicate vertical permeability high enough to permit recharge in areas where runoff is not rapid.
	Jefferson City Dolomite	0-220	Thin-bedded, finely to medium-crystalline, argillaceous dolomite with numerous intervals of thick-bedded, massive, cherty, brown dolomite. Some thin, interbedded green shale locally present.	
	Roubidoux Formation	0-180	Finely to medium-crystalline, thin- to thick-bedded, cherty dolomite with intervals of fine- to medium-grained dolomitic sandstone. Locally characterized by ripple marks, mud cracks, and breccia zones.	Moderate to good horizontal and vertical permeability. Wells yield 1-50 gpm. Ponds and lakes in this formation often do not hold water. Many losing stream segments in this formation.
	Upper Gasconade Dolomite	0-100	Finely to coarsely crystalline, vuggy, massive, light-brownish-gray dolomite; relatively chert free.	Good horizontal and vertical permeability. Wells finished in this interval yield 20-75 gpm. Reports of yields as high as 150 gpm are not uncommon, but are unsubstantiated. Units contain numerous caves, springs, and other karst features, and are important in evaluating surface-water-groundwater relationships in the basin study area. Stratigraphically, the lowest unit cropping out in the study area is Lower Gasconade Dolomite.
	Lower Gasconade Dolomite	205-385	Finely to medium-crystalline, thin- to medium-bedded, cherty dolomite. Cryptozoon reef masses and thin sandstone bodies are locally present.	
	Gunter Sandstone mbr.	10-45	Medium-grained sandstone with dolomitic cement; becomes more dolomitic in the western part of the study area. Sandstone content varies between 20% and 100%.	
Cambrian	Eminence Dolomite	240-600(?)	Medium- to coarsely crystalline, medium-bedded to massive dolomite. Small amounts of chert present, primarily in the upper part of formation.	This unit not an important aquifer in the study study area. Yields to wells are 6-100 gpm, the average being about 20 gpm.
	Potosi Dolomite	90-330	Finely to medium-crystalline, massively bedded brownish-gray cherty dolomite; contains abundant quartz druse.	This unit an important aquifer for wells in the study area. Tests indicate yields of 80-750 gpm from wells finished in the Potosi. When several aquifers are open to a well, yields as high as 500 gpm are possible.
	Derby-Doerun Dolomite	80(?)-215	Alternating thin- to medium-bedded dolomite, thin-bedded siltstone, and shale; dolomite is fine grained, silty and argillaceous. Glauconite locally present in the lower part of formation.	This interval is not important as an aquifer in the study area.
	Davis Formation	50-380(?)	Siltstone, fine-grained sandstone, dolomite, and shale, with limestone conglomerate locally present. Siltstone and sandstone contain glauconite.	
	Bonneterre Formation	85-200	Finely to medium-crystalline, medium-bedded dolomite and limestone. In study area, limestone constitutes 40% to 90% of the carbonate fraction of the formation. Unit relatively chert free.	Inconclusive information concerning yields, but interval probably not to be considered an important source of water in the study area.
	Lamotte Sandstone	140-300	Fine- to medium-grained sandstone. Locally grades laterally into arkosic material. Conglomeratic material locally at base, overlying Precambrian. Thickness of arkosic conglomerate ranges from 0-60 ft.	Only three wells in the study area penetrate this unit; units from the Eminence through Lamotte are uncased. Average yields for the Lamotte are 100-200 gpm; total yields from wells are 480-500 gpm.
Precambrian	Igneous and Metamorphic Rocks			Not important as a source of water in the study area.

material. At times, reefs formed lagoons in which detrital materials were deposited and beds of sandstone alternate with reef deposits. In general, however, the depositional environment through the Cambrian and Ordovician continued to be one in which carbonates were deposited, resulting in a rock sequence amenable to later widespread dissolution, with few beds to interrupt free circulation of water to a depth of 1000 ft or more.

Cambrian Rocks

Cambrian rocks are 1200 ft thick at Lebanon and thin to about 700 ft at the western side of the area. They are predominantly dolomite, with lesser thicknesses of limestone, siltstone, and sandstone occuring principally below the Potosi Dolomite. The Cambrian dolomite above the shale of the Davis Formation is massive, with little shale or sandstone. Quartz druse is present in the Eminence Dolomite and abundant in the Potosi; it usually indicates permeable conditions. Chert is less abundant than in the overlying Ordovocian formations. The Derby-Doerun Dolomite, at the base of the Potosi Dolomite, contains more siliceous material here than elsewhere in Missouri; it constitutes the uppermost limit of the predominantly clastic materials encountered in the Cambrian. The underlying Davis Formation contains the only persistent confining shale bed in the Cambrian section. The Potosi Dolomite, the principal aquifer in the Ozarks and the project area, is 250 ft thick at Lebanon and thins to 100 ft in the western part of the project area.

Ordovician Rocks

The Gunter Sandstone Member, at the base of the Lower Gasconade Dolomite, is stratigraphically the oldest Ordovician rock unit in the study area. The lithofacies map of the Gunter (fig. 10) shows the percentage of sandstone in the unit; it also indicates structural control of sandstone distribution, inasmuch as the northwest trend of variations in sandstone percentages parallels faulting and axes of warping in the area (Knight, 1954). The Gunter Sandstone is not exposed in the project area.

Although the Upper and Lower Gasconade Dolomite are recognized as separate units in well logs, they were combined in mapping for this report. A principal difference between them is the abundance of chert in the lower unit and its sparsity in the upper. Their combined thickness is between 300 and 400 ft.

The Roubidoux Formation is often recognized by the sandstone beds in it. In the project area, however, sandstone is not as prominent as in some parts of the Ozarks. Much of the Roubidoux is dolomite and chert, the chert content often exceeding 20 percent of the formation (Carver, 1961). Where the Roubidoux does not crop out, it may be as much as 180 ft thick.

The Jefferson City and Cotter Dolomites are often separated in well logs, but they were combined in areal geologic mapping for this project. Sedimentary structures in the Cotter-Jefferson City indicate frequent fluctuations of sea level, which led to formation of conglomerates, sedimentary pinchouts, lenses of cross-bedded sandstones, and mud cracks. The Jefferson City contains more clastic and siliceous material than the Cotter, but the latter is locally argillaceous; their combined thickness in the project area approaches 400 ft.

Mississippian Rocks

Mississippian rocks are limited to the divide in the extreme southern part of the study area and are unimportant to

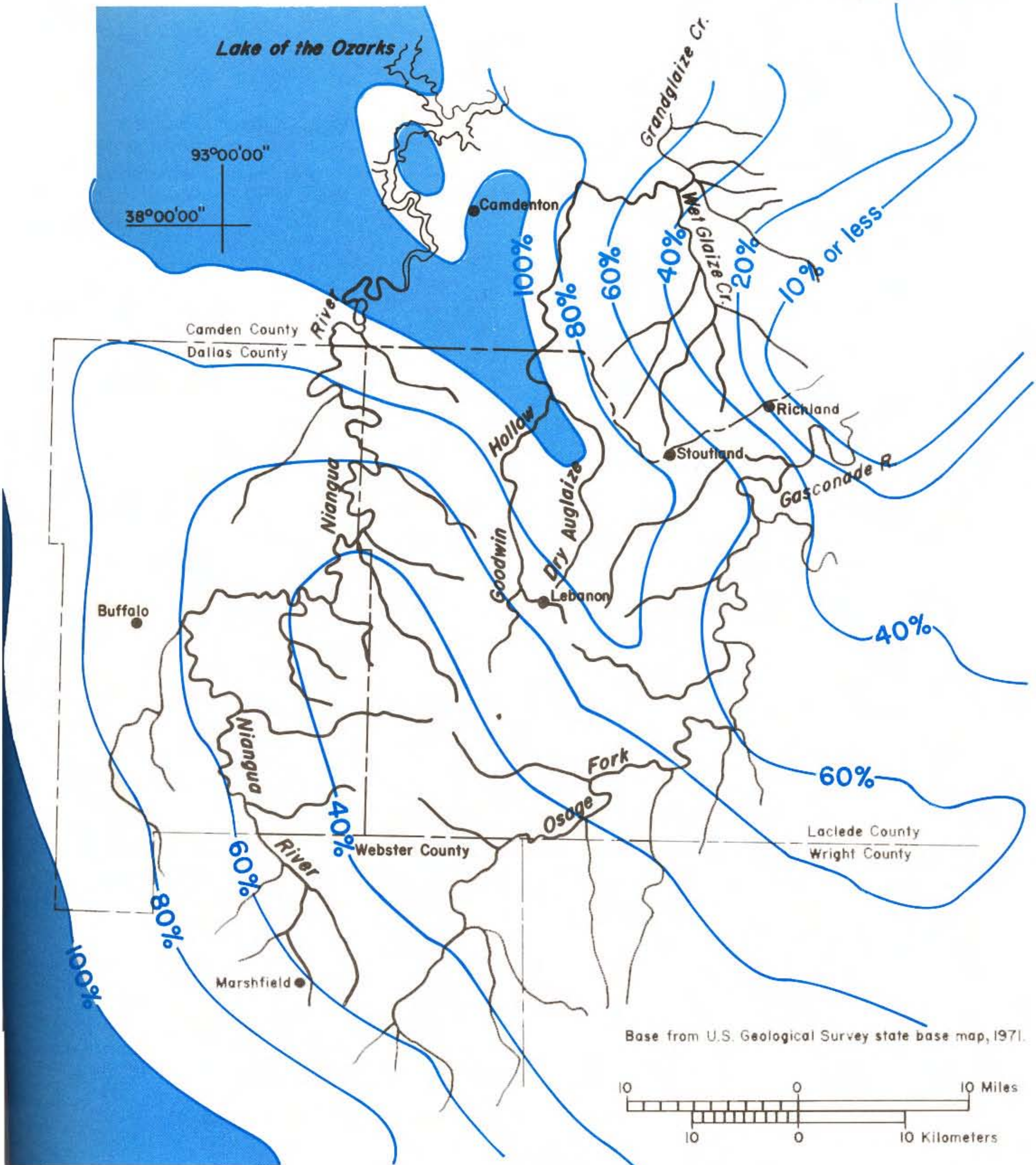


Figure 10. Lithofacies map of the Gunter Sandstone Member of the Lower Gasconade Dolomite. Contours indicate sandstone percentages.

area hydrology. They lie unconformably on the Ordovician sequences described above. Uplift and widespread erosion at the end of the Silurian (Snyder, 1968) account for the lack of Silurian and Middle and Upper Ordovician rocks in the Niangua basin.

Uplift and removal of Mississippian sediments from much of the Ozarks and of Devonian rocks from the study area, antedated a Pennsylvanian submergence. Subsequent Pennsylvanian sediments were eroded without trace in the study area.

Alluvium, Colluvium, and Upland Residuum

Surface soils in the area are classified as residual, alluvial, and colluvial. Colluvial soil development on the lower valley slopes is very limited. Alluvial soils are not extensive in the narrow valleys in the project area. Residual soils developed on the Roubiduox Formation and the Jefferson City and Cotter Dolomites in the uplands usually have a fragipan 18-24 in. below the surface, a feature that retards percolation of water to bedrock; it is more continuous on the Jefferson City and Cotter Dolomites than on the Roubidoux. Water is transmitted horizontally on top of the fragipan except where it is cut by gullies or valleys.

Residual soils developed on the Roubidoux are stonier, less plastic, and allow more efficient percolation than soils on the Jefferson City. Chert beds derived from the Cotter Dolomite locally contribute to high permeability of Cotter-derived soils. The total soil column on the Roubidoux consists of alternating zones of gravelly, sandy clay, and broken chert layers having a very low clay content. Horizontal permeability, therefore, is also extremely high, particularly in the cherty gravel zones.

Structure

The most prominent structural features in the project area are northwest-trending faults, possibly with roots in Precambrian rocks, that are believed to have been active as recently as Middle Ordovician time (K.H. Anderson, Missouri Department of Natural Resources, Division of Geology and Land Survey, oral communication, 1977) (fig. 11, in pocket). Vertical displacements along them range from 10 ft to as much as 400 ft. Several grabens and horsts were formed, of which the most noteworthy, hydrologically, is the horst crossing Steins Creek in the Osage Fork basin (fig. 11, in pocket); another is the graben containing the junction of Dry Auglaize Creek and Goodwin Hollow.

Northeast-trending faults are less prominent, younger, and were probably active between the Mississippian and Pennsylvanian. They appear to be high-angle faults with more horizontal than vertical displacement (C.E. Robertson, Missouri Department of Natural Resources, Division of Geology and Land Survey, oral communication, 1977).

Associated with the major faults are numerous smaller, connecting faults and flexures produced when the major structures were formed. Displacement along minor faults is small, ranging between 5 and 30 ft. Closure on flexures is also low. Fractures and joints with no apparent displacement are abundant. Some of the fractures are related to major structural development in the Ozarks; others may be the result of erosional unloading following uplift of the region (Currie, 1977).

Location and direction of major drainage were influenced by warping, faulting, and jointing. Streams were

deflected and misfits between streamflow and basin size developed. Dissolution of the dolomitic rocks, leading to development of secondary permeability, is another result of the shattering produced by movement. Type of rock involved, strength and duration of deforming forces, chemical character of groundwater moving through crevices, and position of each affected rock unit in relation to changing base levels of erosion are also contributing factors.

In the eastern part of the project area, the rocks have a northward regional dip of 31 ft/mi; in the western part, they dip westward 25 ft/mi.

Erosional unconformities and hiatuses are important features in studying carbonate-rock hydrology, because when carbonate sediments are subaerially exposed, dissolution removes some of them.

An erosional interval marks the close of Cambrian deposition. It is questionable, however, that significant dissolution occurred during this interval in the project area. The actual time boundary (systematic boundary) undoubtedly is somewhere in the upper part of the Eminence Dolomite and should coincide with evidence of structural activity in Missouri (Snyder, 1968). Difficulty in identifying the boundary has led to adoption of the base of the overlying Gunter Sandstone Member of the Gasconade Dolomite as the stratigraphic base of the Ordovician.

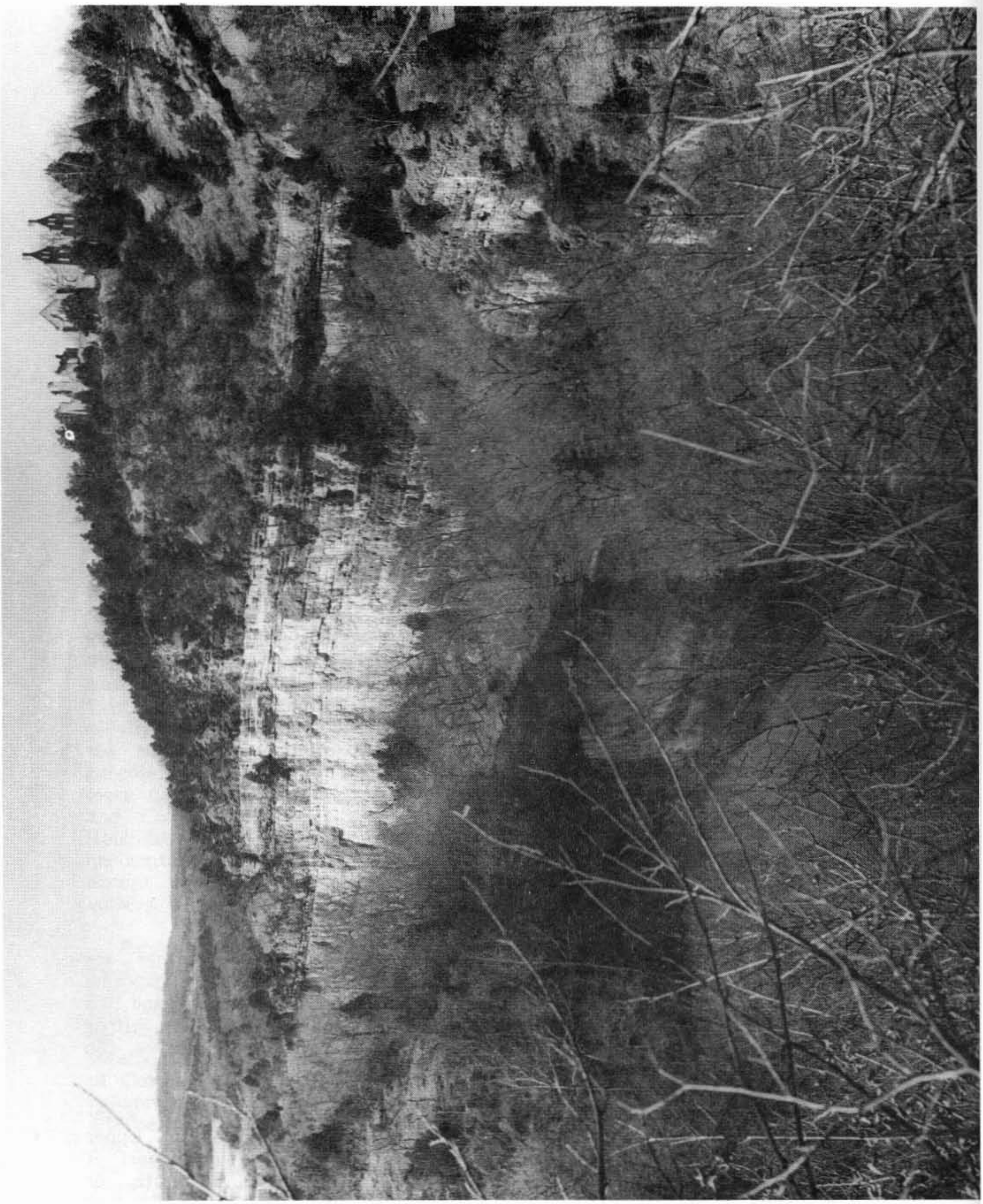
An important period of erosion, leading to extensive dissolution, is the long interval when all post-Early Ordovician sediments were eroded before deposition of the Mississippian limestones. Erosion began after deposition of these limestones, now present only on the southern border of the project area (fig. 4, in pocket), and is continuing. Therefore, it seems probable that much of the dissolution leading to the karst character of the Ozarks was post-Early Ordovician.

GROUNDWATER

DESCRIPTION OF AQUIFERS

All rock units listed in table 1 are locally capable of yielding water to wells in the area. Certain units, such as the Roubidoux Formation, Lower Gasconade Dolomite, Gunter Sandstone Member of the Gasconade Dolomite, and Potosi Dolomite, are more productive than others and are therefore commonly used. They are readily recognized in outcrops and in well cuttings. Springs are common where the units are exposed; depending on valley altitudes and the depth to the zone of saturation, either losing or gaining stream reaches can occur in such outcrop areas.

Many domestic wells obtain water from the Roubidoux Formation, Upper Gasconade Dolomite, or upper part of the Lower Gasconade Dolomite, or combinations of these units. Average



yields of wells completed in these aquifers are 15 to 20 gpm; specific capacities range from 0.10 to 0.40 gpm per foot of drawdown.

Wells penetrating the deeper aquifers, the lower part of the Lower Gasconade Dolomite, Gunter Sandstone Member, Eminence Dolomite, Potosi Dolomite, and Lamotte Sandstone yield up to 750 gpm and have specific capacities ranging from 0.90 to 20 gpm per foot of drawdown; wells penetrating the Potosi have higher specific capacities. The large springs in and just outside the study area are in Lower Gasconade and Eminence rocks (plate 9). Many other solution features, such as caves, sinkholes, and natural bridges, are also associated with these major springs (plate 10).

◀
Plate 9.
Exposure of Lower Gasconade Dolomite, Gunter Sandstone Member of the Lower Gasconade, and Eminence Dolomite at Hahatonka Spring, sec. 2, T. 37 N., R. 17 W. Photograph by James E. Vandike.

▶
Plate 10.
Natural Bridge just east of Hahatonka Spring. The large sinkhole pictured in plate 6 is on the other side of the bridge in this view. The rock is Eminence Dolomite, with the Gunter Sandstone Member of the Lower Gasconade Dolomite near the top of the bridge, sec. 2, T. 37 N., R. 17 W. Photograph by James E. Vandike.

TABLE 2

Transmissivities and storage coefficients of aquifers and specific capacities of wells

Owner or user	Location	Principal aquifer	Static water level (ft)	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm per ft of drawdown)	Transmissivity (ft^2/d)
Shell Pipeline Company	33-19-17cbd	Roubidoux	105	29	3	9.7	---
Robert Stevens	34-15-2bcd	"	150.3	36	7	5.1	---
H.R. Grafton	34-19-33abd	"	145.1	11	48	.03	---
James Sullivan	35-15-10add	"	94.6	10	40	.25	---
Earl York	36-13-8dbd	"	90.3	7	30	.23	---
Lynn Bohannon	36-13-8dab	"	68	27	72	.38	---
Bardette Carnes	36-13-19baa	"	75	20	60	.33	---
E.R. Ravenscroft	38-13-30aba	"	170.3	15	40	.38	---
Russell Hood	31-14-17ccc	Gasconade	200.2	25	40	.62	---
Gordon Knight	32-17-10cbb	"	124.7	35	100	.35	---
Conway High School	32-17-8ccd	"	150.3	7.5	20	.38	---
Peter Atkinson	33-17-7ddd	"	205.0	20	20	1.0	---
Robert Pruitt	34-15-22dad	"	288.1	21	30	.70	---
Cliff Springs Camp	35-14-1adb	"	80.1	50	6	8.3	---
L.H. Bryant	35-16-10daa	"	171.1	10	10	1.0	---
Archie George	36-16-23aaa	"	125	10	25	.4	---
R-6 School	31-15-17aa	Gunter	216.0	22	10	2.2	---
Laclede County PWSD 3, Well 3	33-17-22da	"	327	60	120	.5	230
U.S. Civilian Conservation Corps	34-13-20daa	"	272.0	25	11	2.3	---
Fred Adams	36-18-31ba	"	90	1,140	22	52	---
Ozark Fisheries (Hurt Well)	37-15-25	Gunter(?)	39.8	615	186.2	3.3	300
Ozark Fisheries (Ash Well)	36-15-25bda	"	10.6	660	114	5.8	---
City of Marshfield, Well 2	30-18-3cdc	Potosi	254.4	590	58.5	10	1,730
City of Conway	32-17-8dcc	"	172.8	183	104	1.8	---
Laclede County PWSD 3, Well 2	33-16-9aa	"	405.2	115	33.1	3.5	240
Laclede County PWSD 1, Well 3[1]	33-17-1dd	"	504.0	175	62.0	2.8	510
Laclede County PWSD 1, Well 1	33-17-1ddd	"	359.0	185	35.0	5.3	720
Laclede County PWSD 1, Well 2	34-16-2ba	"	---	167	46	3.6	1,200
City of Lebanon, Well 4	34-16-3dcb	"	345.1	480	65	7.4	---
Mid-America Dairy	34-16-10dc	"	348.8	260	60	4.3	---
Frisco Railroad	34-16-11bac	"	345	300	67	4.5	---
City of Lebanon, Well 3	34-16-11cad	"	335	495	150	3.3	960
City of Lebanon, Well 5	34-16-14abb	"	383.2	500	122	4.1	---
City of Buffalo, Well 2	34-20-26adb	"	172	205	53	3.9	---
City of Buffalo, Well 3	34-20-26aba	"	186.1	200	68.3	2.9	410
Missouri Highway Department Rest Stop	35-17-31bcc	"	14.8	100	15	6.7	---
City of Richland, Well 1	36-13-7ccd	"	252.4	100	5	20	---
City of Richland, Well 3	36-13-8	"	263.0	500	113.8	4.4	410
City of Richland, Well 2	36-13-18abc	"	240	210	50	4.2	---
Ozark Fisheries, Squirrel Well	36-14-6abc	"	52.7	753	45	17	---
Laclede County, PWSD 2, Well 1	36-14-31bad	Potosi	263.3	68	84.3	.8	270

[1]Storage coefficient equals 0.0002

The higher yields of the lower aquifers result from several interrelated factors:

1. The lower zones are brittle, massive, cherty dolomite with little silt or clay and fracture cleanly.
2. Residue from solution is small and circulation is not impeded (Reesman and others, 1975).
3. The productive zones are below the base level of erosion and the present zone of water-level fluctuation; hence, pore spaces are always saturated (Sokolov, 1967).
4. High hydrostatic pressure and mixing of water from more than one source promote dissolution of dolomite and limestone (Jakucs, 1977).

The major streams in the study area have cut only as deep as the lower part of the Lower Gasconade, and this only in the extreme northern part of the area. It is possible that even though high permeabilities might exist locally in the upper, less productive rocks, water is not permanently stored in them, because of drainage to local streams. The Lower Gasconade becomes less productive nearer its outcrop in the Niangua drainage, as does the Gunter Sandstone Member in outcrops just outside the northern boundary of the study area. One explanation of this phenomenon could be a reduction in the secondary permeability of these rocks by deposition of $CaCO_3$ (calcium carbonate) in the pore spaces, because of a change in groundwater gradients near the outcrop (Burdon, 1967). More study is needed to verify this change in permeability and its effect on well yields.

Yields of many of the large-capacity wells in this area are lower than those of comparable depth in surrounding areas. Transmissivities of aquifers in the project area range from 240 to 1730 ft^2/d (table 2); the higher transmissivities and specific capacities are in the southwestern part and across the northern margin of the study area (fig. 12 and plate 11). Some evidence suggests these productive areas resulted from uplift and erosion at the end of the Mississippian. There are higher transmissivities in Cambrian-Ordovician rocks in Missouri, along such structural trends as the Early Pennsylvanian Bourbon arch (D.L. Fuller, Missouri Department of Natural Resources, Division of Geology and Land Survey, oral communication, 1977). The lowest specific capacities are in the south-central part of the study area (fig. 12).

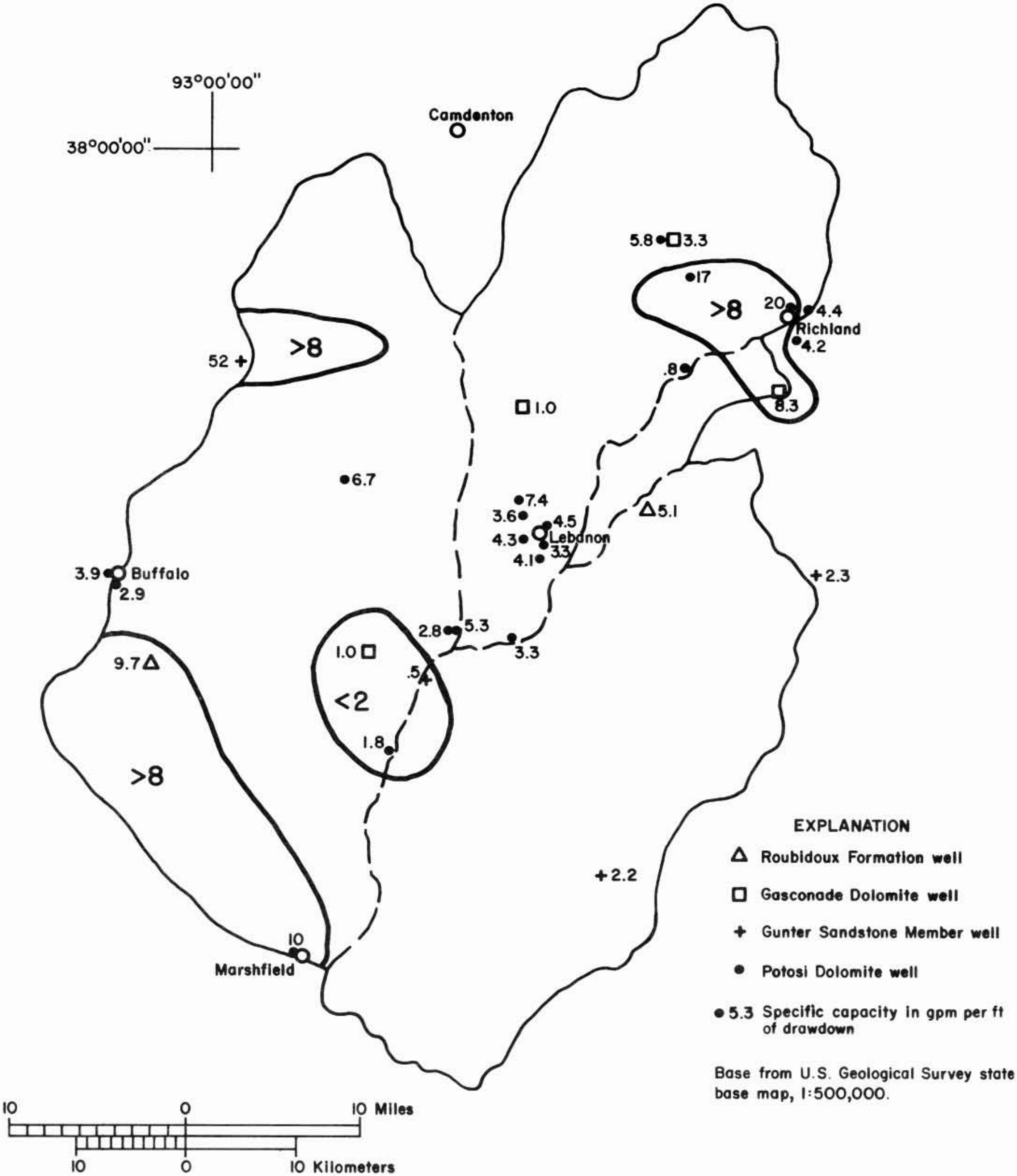
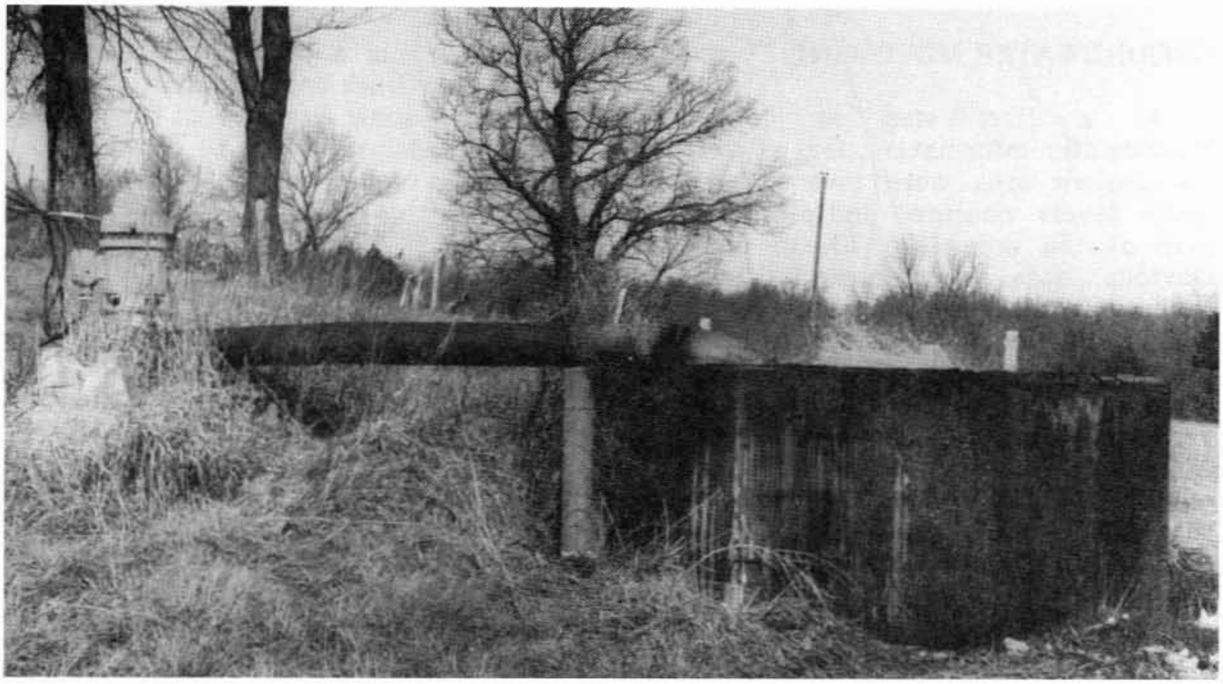


Figure 12. Areal variation in specific capacities of high-capacity wells. Yields greater than 30 gpm.



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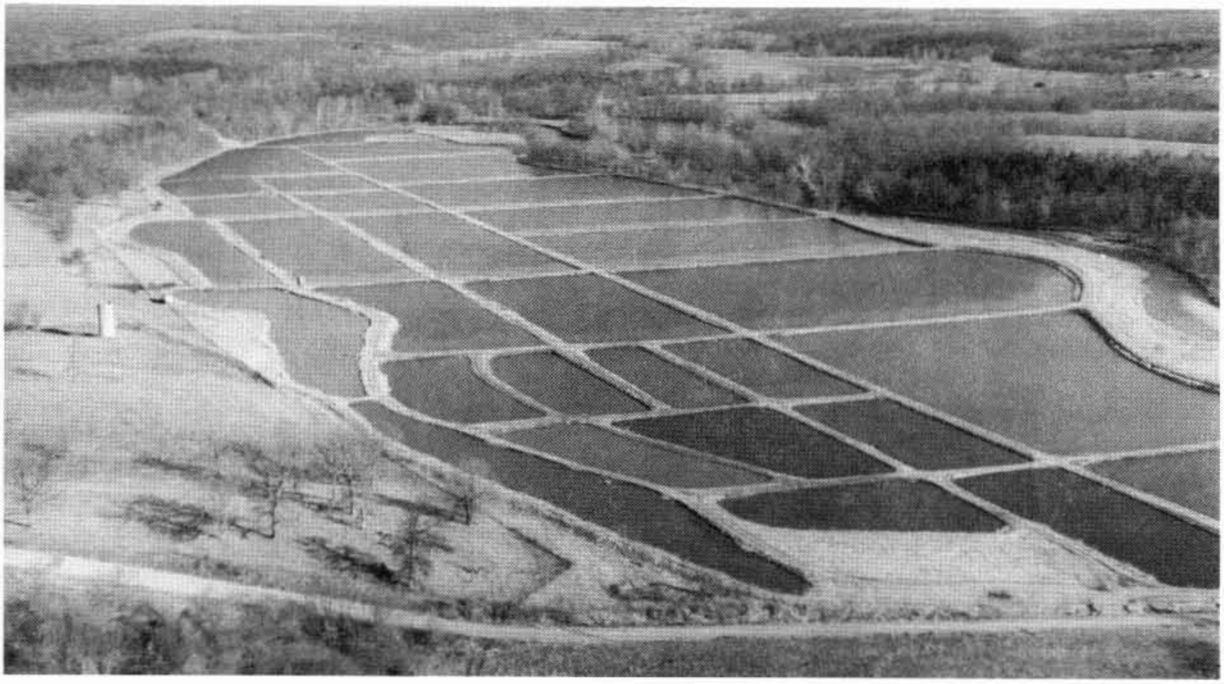

B

Plate 11. 11A is a view of a high-capacity well, with a capacity of 615 gpm and a transmissivity of 300 ft^2/day, in the northern part of the study area, at Ozark Fisheries, sec. 25, T. 37 N., R. 15 W., Camden County. 11B is an aerial view of fish ponds, at Ozark Fisheries, filled with water from high-capacity wells, springs, and Mill Creek. Photographs by James E. Vandike.

GROUNDWATER MOVEMENT

As a first step in collecting groundwater information, logged wells in the project area were inventoried and water levels measured and plotted on a map of the area (fig. 13, in pocket). Obvious data gaps were filled by revisiting unlogged wells and measuring their water levels. Recent data indicate that configuration of the potentiometric surface in the project area has changed very little in the past 30 to 40 years, except for some lowering in areas of municipal pumpage. Table 3 lists wells that provided data for this study; figure 14 (in pocket) shows their locations.

There are advantages and disadvantages in construction and use of potentiometric maps for carbonate aquifers. Contour shapes can indicate areas of significant water loss in surface streams like those in Dry Auglaize Creek basin; however, areas where more subtle losses occur cannot be detected from contouring alone, because contour intervals are usually too large. Groundwater levels only a few feet below stream level at the time of measurement result from vertical groundwater movement and streamflow loss not reflected in contouring.

Because water levels may differ in wells of various depths in any specific area, potentiometric maps must be considered subjective if drawn only on the basis of selected wells of specified depth or of wells completed in a particular stratigraphic unit. Construction of such maps does not fully take into account areal variations of vertical permeability, because groundwater may move through conduits at various angles to the generalized flow pattern. However, these factors do not detract from the principal purpose of potentiometric maps: to show the general direction of groundwater movement.

Figure 15 is a map constructed by drawing flow lines on the potentiometric map; arrows show direction of flow. The following conclusions can be drawn from examination of this map:

a. The groundwater divide as indicated by the flow lines conforms approximately to the surface drainage divide between the Niangua River and Osage Fork.

b. Groundwater movement is generally toward the principal streams in the area: the Niangua River, Osage Fork, and Grandglaize Creek.

c. Runoff from the Niangua River is increased by groundwater flowing from the upper Dry Auglaize Creek basin and perhaps by a very small amount from the Osage Fork basin.

d. As indicated by the southernmost flow lines, some groundwater flow from the drainage area of the Osage Fork may be reaching the Gasconade River.

e. Groundwater and surface-water flow systems of Ozark basins are interdependent; anything natural or artificial affecting hydrology in one basin may affect it in others.

As shown in the following table, there appear to be at least three, perhaps four, separate potentiometric surfaces in upland areas:

Sequence of formations penetrated by wells	Range in depth to water, in feet	Average depth to water, in feet
Jefferson City Dolomite	20-90	50
Jefferson City Dolomite—Roubidoux Formation	18-205	100
Roubidoux Formation—Gasconade Dolomite	14-300	150
Eminence Dolomite—Lamotte Sandstone	15-407	200

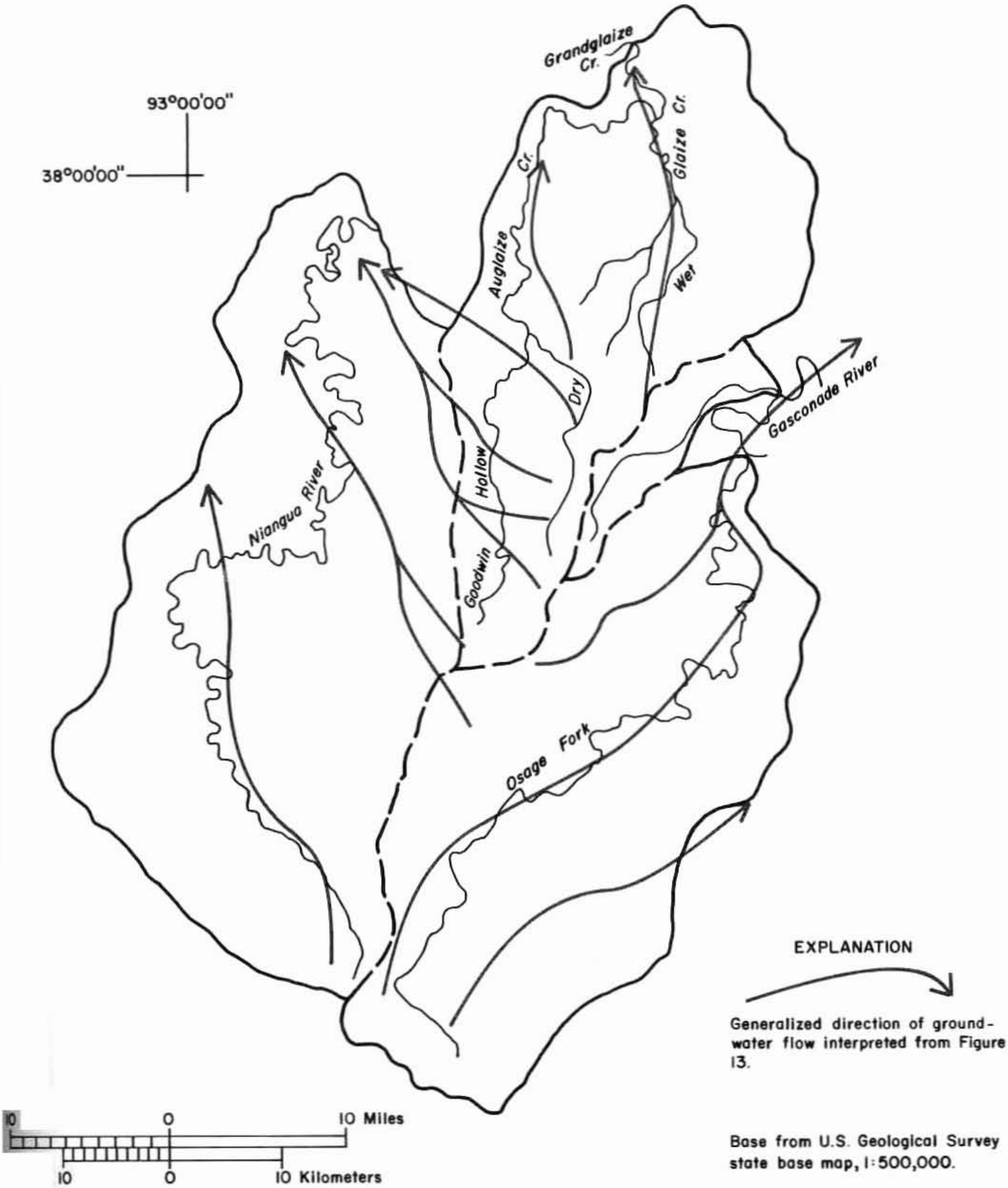

Figure 15. Generalized directions of groundwater flow in the Niangua River, Osage Fork, and Grandglaize Creek basins.

TABLE 3

Record of wells in the project area

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity (gpm/ft)	Principal aquifer
Johnson, C.R.	T29N R18W 05BBC1	Webster	10096	01/01/1948	1350	206	45	6	174.00	01/01/1948	—	—	367CTTR
Friendship Baptist Church	T29N R19W 01BDA1	Webster	25095	01/01/1967	1400	191	23	6	106.00	01/01/1967	11	—	368JFRC
Boyer, Truel	T30N R15W 17AAA1	Wright	23216	01/01/1964	1516	118	20	6	33.00	01/01/1964	5	—	368JFRC
Hutton, Mrs. E.	T30N R16W 10BBB1	Wright	25981	01/01/1967	1450	150	37	6	50.00	01/01/1967	5	—	368JFRC
Bunn, Flete	T30N R16W 23AAA1	Wright	22268	01/01/1963	1568	160	76	6	90.00	01/01/1977	4	—	368JFRC
Rolf, E.W.	T30N R16W 24ABC1	Wright	25510	01/01/1967	1510	200	—	6	—	—	—	—	367RBDX
Sherman, Roy	T30N R17W 02	Webster	27640	01/01/1971	—	285	—	—	—	—	—	—	367RBDX
Dyche, W.C.	T30N R17W 05BDA1	Webster	24073	01/01/1965	1304	112	21	6	36.00	01/01/1977	25	—	368JFRC
Camp Arrowhead	T30N R17W 08DAD1	Webster	20936	01/01/1962	1439	500	175	6	125.00	01/01/1962	33	—	367RBDX
Parsons, Ken	T30N R17W 35BAC1	Webster	13269	01/01/1954	1461	250	34	5.60	65.20	01/01/1954	—	—	368JFRC
McVay, Ken	T30N R18W 01ABA1	Webster	25739	01/01/1967	1460	322	78	6	18.00	01/01/1967	33	—	367RBDX
Letterman, Paul	T30N R18W 01BDB1	Webster	26147	01/01/1967	1410	152	20	6	43.00	01/01/1967	10	—	368JFRC
Rueter, H.H.	T30N R18W 02DC	Webster	26144	01/01/1968	1432	146	33	6	57.10	01/01/1968	9	—	368JFRC
Marshfield #2	T30N R18W 03CDC1	Webster	9765	12/01/1947	1485	1340	362	12	254.00	12/ /1947	590	10.1	367GNTR
Standard Oil	T30N R18W 04CBB1	Webster	26552	01/01/1970	1489	505	300	6	80.20	01/01/1970	30	—	367RBDX
Marshfield 3	T30N R18W 10	Webster	27990	01/01/1976	—	1420	425	10	233.10	01/01/1976	—	—	371POTS
Marshfield #1	T30N R18W 10ABB1	Webster	2114	1926	1487	940	300	8	200.00	1926	173	—	367GSCD
Consol Products	T30N R18W 10BDB1	Webster	8583	01/01/1944	1486	1350	371	8	210.00	01/01/1944	500	—	371POTS
Pevely Dairy	T30N R18W 11BBC1	Webster	2279	01/01/1930	1480	965	78	8	190.00	01/01/1930	200	—	367GNTR
Bell, Roy	T30N R18W 17DDB1	Webster	25299	01/01/1965	1433	165	42	6	65.00	01/01/1965	10	—	368JFRC
Graves, Roy	T30N R18W 19CDC1	Webster	25743	01/01/1967	1380	145	14	6	28.00	01/01/1967	8	—	368JFRC
Crawford, Bill	T30N R18W 22CAA1	Webster	25108	01/01/1967	1550	315	39	6	217.30	01/01/1967	23	—	368JFRC
Erb, F.A.	T30N R18W 25AAA1	Webster	4512	01/01/1937	1435	150	13	6	111.00	01/01/1937	—	—	368JFRC
Linder, H.W.	T30N R18W 26CCB1	Webster	25746	01/01/1967	1537	450	22	6	160.00	01/01/1967	16	—	367RBDX
Montgomery, H.P.	T30N R18W 33CAB1	Webster	27173	01/01/1968	1485	181	40	6	26.00	01/01/1968	15	—	367RBDX
Hood, Russell	T31N R14W 17CCC1	Wright	25246	01/01/1967	1323	385	49	6	200.20	01/01/1967	25	0.6	367GSCDL
Hood, Russell	T31N R14W 18DCA1	Wright	25093	01/01/1966	1209	275	19	6	21.00	01/01/1966	20	—	367RBDX
Hood, Russell	T31N R14W 19BBA1	Wright	25248	01/01/1967	1255	380	117	6	100.00	01/01/1967	18	—	367GNTR
Edgerton, R.E.	T31N R15W 05DBB1	Wright	27182	01/01/1969	1380	246	38	6	171.30	01/01/1969	12	—	367GSCDL
Guinn, Darrell	T31N R15W 06DDC1	Wright	21769	01/01/1963	1359	220	41	6	139.00	01/01/1963	18	—	367GSCDU
Guinn, J.D.	T31N R15W 08AAD1	Wright	27068	01/01/1969	—	227	40	6	110.40	01/01/1973	12	—	367GSCDL
Guinn, Velmer	T31N R15W 08ADC1	Wright	21771	01/01/1963	1345	225	30	6	111.90	01/01/1963	10	—	367GSCDL
Bratton, J.E.	T31N R15W 16ADB1	Wright	26155	01/01/1967	1405	320	169	6	240.80	01/01/1967	5	—	367GSCDL
Robertson, Doyle	T31N R15W 16DCB1	Wright	21810	01/01/1963	1428	221	117	6	151.00	01/01/1963	10	—	367RBDX
R6 School District	T31N R15W 17AA	Wright	20204	01/01/1961	1369	650	200	6	216.00	01/01/1961	22	2.2	371EMNC
Kilmer, Lloyd	T31N R15W 17ACA1	Wright	22062	01/01/1963	1325	170	29	6	66.80	01/01/1963	39	—	367GSCDU
Weaver, Dwight	T31N R15W 17BCB1	Wright	27101	01/01/1969	1315	235	37	6	165.90	01/01/1969	25	—	367GSCDL
Henderson, Thomas	T31N R15W 18ADA1	Wright	25101	01/01/1967	1270	237	41	6	100.30	01/01/1967	20	—	367GSCDL
Pollard, E.	T31N R15W 19BAA1	Wright	27117	01/01/1968	1300	403	169	6	293.00	01/01/1968	20	—	367GSCDL
Barlow, T.C.	T31N R15W 21CDD1	Wright	24805	01/01/1966	1431	126	—	—	48.80	01/01/1966	3	—	367RBDX
Dierks, Robert	T31N R15W 29BAC1	Wright	23394	01/01/1965	1354	202	37	6	55.00	01/01/1965	10	—	367RBDX
Warren, Carol	T31N R15W 32CBB1	Wright	13812	01/01/1955	1426	220	68	6	59.90	01/01/1955	10	—	367RBDX
New Shaddy Church	T31N R15W 33CDB1	Wright	23140	01/01/1964	1466	211	42	6.25	81.30	01/01/1964	23	—	368JFRC
Miller, George	T31N R16W 03CAA1	Wright	25744	01/01/1967	1290	100	21	6	19.00	01/01/1967	50	—	367RBDX

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Milam, Paul	T31N R16W 06ACC1	Webster	24802	01/01/1968	1280	176	26	6	62.00	01/01/1968	30	—	367RBDX
Vestal, Larry	T31N R16W 06BAB1	Webster	21788	01/01/1963	1261	151	41	6	96.00	01/01/1963	28	—	367RBDX
George, David	T31N R16W 09CCB1	Webster	22020	01/01/1963	1373	176	32	6	56.00	01/01/1963	35	—	368JFRC
Dalls, N.T.	T31N R16W 12BCA1	Wright	25058	01/01/1967	1330	186	—	—	55.00	01/01/1967	6	—	367GSCDU
Williams, John	T31N R17W 20ACA1	Webster	—	01/01/1947	1375	135	31	6	67.00	01/01/1947	4	—	367RBDX
Niangua, City No. 1	T31N R17W 20BCA1	Webster	24577	01/01/1966	1447	1050	350	8	208.00	01/01/1966	—	—	371EMNC
Sell, James	T31N R17W 20BCB1	Webster	24071	01/01/1965	1438	196	72	6	115.00	01/01/1965	31	—	367RBDX
MFA Exchange	T31N R17W 20CAB1	Webster	23111	01/01/1964	1439	205	182	4.75	85.30	01/01/1964	12	—	367RBDX
Cantrel, Herbert	T31N R17W 25DBD1	Webster	22992	01/01/1963	1397	125	56	6	64.00	01/01/1963	4	—	368JFRC
Hyder, Ganvel	T31N R17W 29CA	Webster	22991	01/01/1964	1421	100	22	6	55.00	01/01/1964	5	—	368JFRC
Gower, John	T31N R18W 06BDB1	Webster	23151	01/01/1964	1278	201	30	6	129.00	01/01/1964	20	—	367RBDX
Odell, Ray	T31N R18W 22DDC1	Webster	26163	01/01/1967	1390	140	48	6	41.70	01/01/1967	10	—	368JFRC
Nelson, Earl	T31N R18W 25AAD1	Webster	25740	01/01/1967	1370	210	22	6	86.10	01/01/1967	9	—	367RBDX
Jump, Robert	T31N R18W 28CBD1	Webster	24801	01/01/1966	1360	201	22	6	78.20	01/01/1966	10	—	368JFRC
Johnson, J.L.	T31N R19W 04CDB1	Webster	22067	01/01/1963	1293	295	36	8	—	—	15	—	367RBDX
Bohannon, Buster	T31N R19W 10CAC1	Webster	24806	01/01/1966	1324	147	31	6	42.30	01/01/1966	9	—	368JFRC
Hobson, Glenn	T31N R19W 36CC	Webster	27707	01/01/1974	1445	500	300	6	220.10	01/01/1974	120	—	367GSCDU
Todd, Melvin	T32N R14W 07BDB1	Laclede	22338	01/01/1963	1257	175	40	6	123.90	01/01/1963	12	—	367RBDX
Beard, Virgil	T32N R15W 01CBD1	Laclede	22478	01/01/1963	1121	141	21	6	76.00	01/01/1963	20	—	367RBDX
Humphries, Leroy	T32N R15W 04ACB1	Laclede	27170	01/01/1969	—	301	59	6	221.10	01/01/1969	9	—	367GSCDL
Meredith, Max	T32N R15W 20DAA1	Wright	24774	01/01/1966	1342	191	96	6	121.20	01/01/1966	33	—	367GSCDL
Moss, O.R.	T32N R15W 21BAB1	Wright	26150	01/01/1967	1337	236	187	6	160.30	01/01/1967	15	—	367GSCDL
Moore, John	T32N R15W 21DCA1	Wright	23139	01/01/1964	1360	175	103	6	119.00	01/01/1964	30	—	367GSCDL
Simmons, Claude	T32N R15W 24AAC1	Wright	11018	01/01/1947	1227	100	27	6	45.00	01/01/1947	—	—	368JFRC
Parker, Ray	T32N R15W 24BCD1	Wright	11081	01/01/1947	1201	40	9	6	—	—	2	—	368JFRC
Kneale, Ray	T32N R15W 28BBC1	Wright	27096	01/01/1968	—	372	155	6	233.80	01/01/1968	20	—	367GSCDL
Long, Earl	T32N R15W 32AAD1	Wright	26145	01/01/1967	1373	350	73	6	243.10	01/01/1967	17	—	367GSCDL
Kneale, Ray	T32N R15W 32DAC1	Wright	23158	01/01/1964	1375	321	99	6.25	239.40	01/01/1964	12	—	367GSCDL
Jackson, Marvin	T32N R16W 01CAC1	Laclede	—	01/01/1950	1280	165	—	6	148.40	01/01/1977	—	—	368CNDN
Kilburn, Henry	T32N R26W 06ABA1	Laclede	11022	01/01/1947	1332	171	33	6.25	—	—	—	—	367RBDX
Campbell, Harold	T32N R16W 06CCC1	Laclede	22022	01/01/1963	1322	251	—	6.25	176.90	01/01/1963	23	—	367GSCDL
Bean, Leonard	T32N R16W 08BBA1	Laclede	22135	01/01/1963	1325	220	92	6.25	176.20	01/01/1963	12	—	367GSCDU
Medlock, William	T32N R16W 19DCB1	Webster	22337	01/01/1963	1257	151	39	6.25	61.80	01/01/1963	26	—	367RBDX
Hileman, D.G.	T32N R16W 27BDC1	Wright	23741	01/01/1965	1345	233	82	6.25	170.20	01/01/1965	10	—	367GSCDL
Ketcherside, C.	T32N R16W 29AAA1	Webster	24771	01/01/1966	1340	261	79	6.25	163.90	01/01/1966	8	—	367GSCDL
Stokes, D.D.	T32N R16W 29BCA1	Webster	23393	01/01/1964	1201	126	39	6.25	61.00	01/01/1964	40	—	367RBDX
Keisling, A.	T32N R16W 29CA	Webster	10701	01/01/1947	1165	83	20	6.25	31.80	01/01/1947	9	—	367RBDX
Kirk, Edwin	T32N R16W 34DCC1	Webster	25067	01/01/1966	1368	211	45	6.25	144.70	01/01/1966	15	—	367GSCDU
Caffey, Billy J.	T32N R17W 02CAD1	Laclede	—	01/01/1956	1320	310	—	6.25	202.70	01/01/1977	—	—	368CNDN
Watkins, Arch	T32N R17W 05ABB1	Laclede	24803	01/01/1966	1376	216	22	6.25	151.40	01/01/1966	22	—	367RBDX
Summers, Leslie	T32N R17W 05CAA1	Laclede	22137	01/01/1963	1392	175	34	6.25	97.20	01/01/1963	7	—	367RBDX
Jacobson, John	T32N R17W 05DDC1	Laclede	22477	01/01/1963	1381	185	99	6.25	91.00	01/01/1963	7	—	367GSCDU
Van Stavern, C.W.	T32N R17W 07BDD1	Laclede	27184	01/01/1970	1360	241	45	6.25	64.00	01/01/1970	35	—	367GSCDL
Williams, Paul	T32N R17W 07DAD1	Laclede	9906	01/01/1947	1376	107	—	—	—	—	—	—	367RBDX
Conway School	T32N R17W 08CCD1	Laclede	6422	01/01/1940	1398	347	215	5.60	150.30	01/01/1940	8	0.4	367GSCDL

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Conway	T32N R17W 08DCC1	Laclede	10715	12/01/1948	1403	954	303	8	173.00	12/01/1948	183	1.8	367GNTR
Knight, Gordon C.	T32N R17W 10BBB1	Laclede	17918	1959	1305	350	102	6	125.00	01/01/1959	35	0.4	367RBDX
Tillman, C.R.	T32N R17W 23DDA1	Webster	9405	01/01/1946	1325	112	—	—	—	—	—	—	367RBDX
Caffey, Ed	T32N R17W 24AAB1	Webster	9907	01/01/1947	1258	77	—	—	—	—	—	—	367RBDX
Miller, W.J.	T32N R17W 25DAC1	Webster	21797	01/01/1963	1277	196	43	6.25	106.00	01/01/1963	30	—	367GSCDU
Kilburn, J.D.	T32N R17W 34DAD1	Webster	24077	01/01/1965	1307	142	20	6.25	77.30	01/01/1965	10	—	367RBDX
Good Springs Church	T32N R17W 35CCC1	Webster	22136	01/01/1963	1265	190	31	6.25	79.10	01/01/1963	32	—	367GSCDU
Vestal, Harold	T32N R17W 36CCD1	Webster	23396	01/01/1964	1224	126	12	6.25	54.00	01/01/1964	12	—	367RBDX
Vestal, Rex	T32N R17W 36DDD1	Webster	21762	01/01/1963	1250	170	21	6.25	87.80	01/01/1963	24	—	367RBDX
Rosenthal, Leon	T32N R18W 01DAC1	Dallas	22132	01/01/1963	1308	170	30	6.25	62.80	01/01/1963	28	—	367RBDX
Knight, Ira E.	T32N R18W 03DDB1	Dallas	17938	01/01/1959	1218	150	53	6.25	29.00	01/01/1959	13	—	367GSCDU
Vincent, Lester	T32N R18W 05ACA1	Dallas	—	01/01/1953	1240	210	40	6.25	121.20	01/01/1977	15	—	368CNDN
Clark, Carl	T32N R18W 12ABA1	Dallas	22131	01/01/1963	1385	165	6	43	104.20	01/01/1963	23	—	367RBDX
Missouri Highway Dept.	T32N R18W 12ADA1	Dallas	21360	01/01/1962	1354	300	138	6.25	72.00	01/01/1962	5	—	367GSCDL
Clark, Carl	T32N R18W 12ADB1	Dallas	25738	01/01/1967	1297	170	42	6.25	62.90	01/01/1967	14	—	367GSCDU
Young, L.E.	T32N R18W 13ABA1	Dallas	15457	01/01/1957	1358	250	—	—	—	—	12	—	367GSCDL
Whitehead, L.R.	T32N R18W 22CAC1	Dallas	25103	01/01/1966	1288	230	39	6.25	124.80	01/01/1966	14	—	367GSCDL
Missouri Highway Dept.	T32N R18W 24DBA1	Dallas	27343	01/01/1970	1360	700	350	6	200.00	01/01/1970	—	—	371EMNC
Long, Virgil	T32N R18W 27BCC1	Dallas	21519	01/01/1962	1255	136	42	6.25	99.00	01/01/1962	3	—	367RBDX
Newman, Glen	T32N R18W 28DAA1	Dallas	21515	01/01/1962	1246	220	40	6.25	132.10	01/01/1962	25	—	367GSCDL
Shook, Lee	T32N R18W 28DBC1	Dallas	23142	01/01/1964	1201	—	38	6.25	81.20	01/01/1964	29	—	367GSCDL
Newman, W.L.	T32N R18W 29AAA1	Dallas	21513	01/01/1962	1201	136	31	6.25	52.00	01/01/1962	17	—	367RBDX
Custer, H.R.	T32N R18W 35BBD1	Dallas	23154	01/01/1964	1326	200	42	6.25	124.70	01/01/1964	12	—	367GSCDL
Penrod, Don	T32N R18W 36BAC1	Webster	25300	01/01/1965	1380	320	22	6.25	120.10	01/01/1965	10	—	367GSCDL
Nunn, Cleo	T32N R18W 36BDB1	Webster	21362	01/01/1962	1373	315	17	6.25	68.00	01/01/1962	20	—	367GSCDL
Price, George	T32N R19W 35CBB1	Webster	22781	01/01/1964	1270	179	22	6.25	100.20	01/01/1964	6	—	367RBDX
Pollock, Marvin	T33N R13W 01ABC1	Laclede	26140	01/01/1968	1230	200	45	6.25	—	—	—	—	367RBDX
Lambeth, Wayne	T33N R14W 07AAA1	Laclede	24379	01/01/1966	1121	178	38	6.25	130.10	01/01/1966	20	—	367GSCDU
Griffin, Dale	T33N R14W 20CBA1	Laclede	—	01/01/1974	1184	300	—	6.25	183.90	01/01/1974	15	—	368CNDN
Rumfelt, Norman	T33N R14W 21CBC1	Laclede	21322	01/01/1962	1114	190	20	6.25	—	—	15	—	367GSCDU
Burris, Mitchell	T33N R15W 05DAA1	Laclede	27114	01/01/1968	1250	260	56	6.25	120.90	01/01/1968	14	—	367GSCDL
Austin, Earl	T33N R15W 06DDD1	Laclede	27082	01/01/1968	1251	302	172	6.25	158.10	01/01/1968	23	—	367GSCDL
Percey, James	T33N R15W 08ABA1	Laclede	—	01/01/1975	1275	320	254	6.25	241.50	01/01/1977	20	—	367GSCDL
McMahan, Bud	T33N R15W 09CDA1	Laclede	—	01/01/1961	1321	255	—	—	214.00	01/01/1961	15	—	368CNDN
Barr, Oren	T33N R15W 12BDB1	Laclede	2172	01/01/1962	1201	185	21	6.25	130.30	01/01/1962	18	—	367RBDX
Noble, Leslie	T33N R15W 26ADC1	Laclede	2313	01/01/1964	1118	151	39	6.25	101.10	01/01/1964	18	—	367GSCDU
Orla Baptist Church	T33N R15W 26DDA1	Laclede	27158	01/01/1969	1035	220	19	6.25	33.00	01/01/1969	20	—	367GSCDU
Plaster, Robert	T33N R15W 28DCD1	Laclede	26151	01/01/1968	1238	346	50	6.25	226.00	01/01/1968	22	—	367GSCDL
Plenner, O.V.	T33N R15W 29DAB1	Laclede	24781	01/01/1966	1282	271	215	6.25	228.70	01/01/1966	21	—	367GSCDL
Mott, Pete	T33N R15W 33AAD1	Laclede	26307	01/01/1967	1232	319	246	6.25	230.80	01/01/1967	12	—	367GSCDL
Orla Mill, Inc.	T33N R15W 33DDA1	Laclede	24808	01/01/1966	1020	151	21	6.25	18.70	01/01/1966	40	—	367GSCDL
Lorance, Ken	T33N R16W 02DCC1	Laclede	23401	01/01/1964	1318	351	186	6.25	255.70	01/01/1964	18	—	367GSCDL
Tyre, Tom	T33N R16W 03DCC1	Laclede	10957	01/01/1947	133(	115	38	6.25	100.00	01/01/1947	8	—	367RBDX
Oliver, L.E.	T33N R16W 05ADC1	Laclede	10705	01/01/1946	135	198	78	6.25	170.00	01/01/1946	5	—	367GSCD

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Kay, W.A.	T33N R16W 05DCB1	Laclede	10669	01/01/1947	1385	145	80	6.25	105.00	01/01/1947	18	—	367GSCDU
Laclede PWSD3 No. 2	T33N R16W 09AAA1	Laclede	26937	01/01/1971	1360	1215	525	8	180.30	01/01/1971	—	—	371POTS
Plummer, Martin	T33N R16W 10CCC1	Laclede	10958	07/29/1947	1274	101	41	6.25	74.00	01/01/1947	1	—	367GSCDU
Adams, James	T33N R16W 11CCC1	Laclede	13544	01/01/1954	1354	395	113	6.25	300.10	01/01/1954	15	—	367GSCDL
Lamkins, Clyde	T33N R16W 14ABB1	Laclede	27207	01/01/1969	1300	452	394	6.25	236.20	01/01/1969	20	—	367GSCDL
Spradling, Robert	T33N R16W 17CCB1	Laclede	—	01/01/1955	1280	297	100	6.25	177.10	01/01/1977	20	—	367GSCD
Robertson, Ron	T33N R16W 22DDB1	Laclede	—	01/01/1970	1220	204	41	6.25	70.00	01/01/1977	12	—	367GSCD
Dillard, James	T33N R16W 24CBA1	Laclede	23896	01/01/1966	1253	140	60	6.25	78.20	01/01/1966	10	—	367GSCDU
Hawk, Keith	T33N R16W 26AAA1	Laclede	25301	01/01/1965	1228	105	68	6.25	48.90	01/01/1966	9	—	367RBDX
Hill, J.L.	T33N R16W 27AAB1	Laclede	22042	01/01/1963	1204	175	42	6.25	58.80	01/01/1963	25	—	367GSCDU
Heften, Gene	T33N R16W 30DBA1	Laclede	22199	01/01/1963	1241	300	80	6.25	225.30	01/01/1963	15	—	367GSCDL
Sharp, Stan	T33N R16W 34DBA1	Laclede	10091	01/01/1948	1284	115	58	6.25	86.30	01/01/1948	3	—	367RBDX
Laclede PWSD1 No. 3	T33N R17W 01DDD1	Laclede	27752	01/01/1974	1410	1200	521	8	407.20	01/01/1974	175	2.8	371POTS
Cook, Robert	T33N R17W 02BBC1	Laclede	22778	01/01/1964	1329	450	105	6.25	259.70	01/01/1964	10	—	371EMNC
Wilson, Richard	T33N R17W 03DDA1	Laclede	—	01/01/1900	1290	305	204	6.25	205.10	01/01/1977	20	—	367GSCDL
Gay, Homer	T33N R17W 04BCC1	Laclede	23168	01/01/1965	1314	325	60	6.25	225.00	01/01/1965	10	—	367GSCDL
Atkison, Peter	T33N R17W 07DDD1	Laclede	23851	01/01/1967	1284	316	225	6.25	205.00	01/01/1967	20	1.0	367GSCDL
Graves, Jack	T33N R17W 10CBC1	Laclede	26153	01/01/1970	1330	125	100	6.25	94.90	01/01/1970	20	—	367RBDX
Barrett, Tom	T33N R17W 12DCA1	Laclede	19193	01/01/1960	1367	229	193	6.25	179.40	01/01/1960	8	—	367GSCDL
Sun DX Service	T33N R17W 22CAA1	Laclede	27141	01/01/1969	1400	406	258	6.25	246.80	01/01/1969	22	—	367GSCDL
Howerton, James	T33N R17W 22CDD1	Laclede	25747	01/01/1967	1400	400	26	6.25	275.10	01/01/1967	18	—	367GSCDL
Laclede PWSD3 No. 3	T33N R17W 22DA	Laclede	26839	01/01/1971	1400	700	425	6	327.30	01/01/1971	60	0.5	371EMNC
Tribble, Homer	T33N R17W 23CCC1	Laclede	3812	01/01/1936	1377	395	43	6.25	265.00	01/01/1936	9	—	367GSCDL
Myers, Raymond	T33N R17W 25DAD1	Laclede	—	01/01/1973	1240	336	200	6.25	243.30	01/01/1977	30	—	367GSCD
Ferrier, Mrs. H.E.	T33N R17W 26ACC1	Laclede	25096	01/01/1967	1314	101	13	6.25	48.10	01/01/1967	6	—	367RBDX
Stasiak, I.J.	T33N R17W 28CAD1	Laclede	24784	01/01/1966	1380	285	214	6.25	210.30	01/01/1966	20	—	367GSCDL
Turner, Henry	T33N R18W 01AAC1	Laclede	—	01/01/1971	1270	363	200	6.25	213.40	01/01/1977	30	—	367GSCD
Howerton, Hershe	T33N R18W 05ADA1	Laclede	25100	01/01/1967	1098	205	23	6.25	85.90	01/01/1967	15	—	367GSCDL
Brown, Eugene	T33N R18W 21ABD1	Laclede	—	01/01/1900	1150	300	50	6.25	111.00	01/01/1977	10	—	367GSCDL
Henso, Lloyd	T33N R18W 26BDD1	Laclede	23135	01/01/1964	1326	181	141	6.25	80.90	01/01/1964	9	—	367GSCDL
Turner, Lloyd	T33N R19W 03ACA1	Dallas	—	01/01/1964	1105	187	28	6.25	107.10	01/01/1977	30	—	368CNDN
Liddell, C.L.	T33N R19W 05CBD1	Dallas	26358	01/01/1967	1188	258	42	6.25	184.70	01/01/1967	15	—	367RBDX
Cheek, Richard	T33N R19W 12CBD1	Dallas	—	01/01/1900	1140	215	—	6.25	125.00	01/01/1977	10	—	367RBDX
Haffke, H.J.	T33N R19W 17ABB1	Dallas	17153	01/01/1958	1189	185	21	6.25	58.10	01/01/1958	10	—	367RBDX
Shell Pipeline	T33N R19W 17CBD1	Dallas	10446	01/01/1948	1130	275	118	8	105.00	01/01/1948	29	9.7	367RBDX
Gillett, Harlan	T33N R19W 25DBB1	Dallas	—	01/01/1973	1240	225	41	6.25	145.20	01/01/1977	15	—	368CNDN
Gregg, Jessie	T33N R19W 35DBB1	Dallas	—	01/01/1966	1160	170	10	6.25	120.40	01/01/1977	20	—	368CNDN
Jones, Guy	T33N R20W 03ADD1	Dallas	—	01/01/1947	1148	174	15	5.60	66.00	01/01/1947	2	—	368JFRC
Eisman, Willard	T33N R20W 03BCD1	Dallas	—	01/01/1955	1136	183	16	6.25	35.00	01/01/1955	8	—	368JFRC
Walker, Charles	T33N R20W 03BDD1	Dallas	—	01/01/1948	1165	215	—	—	90.00	01/01/1948	6	—	367RBDX
Devore, Earl	T33N R20W 21BCC1	Dallas	—	01/01/1967	1171	196	31	6.25	—	—	7	—	368JFRC
Hatfield, H.B.	T33N R20W 23CBC1	Dallas	—	01/01/1963	1168	300	80	6.25	125.00	01/01/1963	25	—	367RBDX
Ravis, Ed	T33N R20W 26DAB1	Dallas	—	01/01/1968	1263	250	21	6.25	150.20	01/01/1977	20	—	367RBDX
Van Ronjellen, G.	T34N R13W 05CBD1	Laclede	23912	01/01/1965	1052	190	25	6.25	84.80	01/01/1965	12	—	367RBDX
Burgess, Buck	T34N R13W 20ABB1	Laclede	26160	01/01/1967	1220	170	31	6.25	70.30	01/01/1967	7	—	368JFRC

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
US CCC F21	T34N R13W 20DAA1	Laclede	3371	01/01/1935	1260	700	454	6.25	272.00	01/01/1935	25	2.3	371EMNC
Wilson, William	T34N R13W 29ACD1	Laclede	23146	01/01/1964	1215	170	40	6.25	75.30	01/01/1964	2	––	368JFRC
Goode, Albert	T34N R13W 31DAA1	Laclede	26156	01/01/1967	1215	200	42	6.25	75.20	01/01/1967	10	––	367RBDX
McLaughlin, R.D.	T34N R13W 32DBD1	Laclede	26165	01/01/1967	1144	212	31	6.25	130.00	01/01/1967	8	––	367GSCDU
Fields, A.M.	T34N R14W 01BCC1	Laclede	23911	01/01/1965	1142	322	31	6.25	205.20	01/01/1965	20	––	367RBDX
Archer, Ronald	T34N R14W 05AC	Laclede	27183	01/01/1968	1000	201	64	6.25	156.40	01/01/1968	27	––	367GSCDU
Sutherland, Herman	T34N R14W 06DA	Laclede	23389	01/01/1964	971	169	22	6.25	75.00	01/01/1964	9	––	367GSCDU
Elom, Homer	T34N R14W 10DBB1	Laclede	22348	01/01/1963	1061	181	17	6.25	148.80	01/01/1963	23	––	367RBDX
Bowman, Farmer	T34N R14W 16CBA1	Laclede	23150	01/01/1964	1039	335	200	6.25	107.10	01/01/1964	30	––	367GSCDL
Peterson, Willard	T34N R14W 18DAB1	Laclede	27185	01/01/1968	960	236	40	6.25	137.30	01/01/1968	8	––	367RBDX
Rhodes, Lester	T34N R14W 23DDB1	Laclede	26152	01/01/1967	1080	195	23	6.25	115.40	01/01/1967	18	––	367RBDX
Zumwalt, Ralph	T34N R14W 24CCA1	Laclede	25291	01/01/1967	1015	250	21	6.25	130.10	01/01/1967	––	––	367GSCDL
Pierce, E.W.	T34N R14W 26DCA1	Laclede	26143	01/01/1966	1145	203	23	6.25	160.10	01/01/1966	15	––	367RBDX
Gasconade C4 School	T34N R14W 26DDA1	Laclede	21133	01/01/1962	1160	230	27	6.25	172.30	01/01/1962	18	––	367RBDX
Swanson, L.D.	T34N R14W 29ADA1	Laclede	23134	01/01/1964	1135	320	24	6.25	151.90	01/01/1964	7	––	367GSCDL
Stephens, Robert	T34N R15W 02BCB1	Laclede	21606	01/01/1963	1158	204	30	6.25	150.30	01/01/1963	36	5.1	367RBDX
Cox, Josephine	T34N R15W 03AAD1	Laclede	21547	01/01/1963	1165	203	35	6.25	147.30	01/01/1963	7	––	367RBDX
Morris, O.E.	T34N R15W 03ADA1	Laclede	24381	01/01/1966	1178	225	29	6.25	159.60	01/01/1966	15	––	367RBDX
Weaver, Ed	T34N R15W 04DAD1	Laclede	––	01/01/1973	1190	400	60	6.25	238.20	01/01/1977	30	––	367GSCDL
Davenport, J.	T34N R15W 06AC	Laclede	25106	01/01/1967	1260	301	47	6.25	223.30	01/01/1967	18	––	367GSCDU
Thomas, George	T34N R15W 06BCC1	Laclede	23141	01/01/1964	1201	206	124	6.25	132.00	01/01/1964	20	––	367GSCDU
McKenzie, Virgil	T34N R15W 06BDD1	Laclede	26154	01/01/1967	1240	300	220	6.25	209.60	01/01/1967	22	––	367GSCDU
Landon, Walter	T34N R15W 06CBD1	Laclede	21346	01/01/1962	1201	220	20	6.25	125.20	01/01/1962	7	––	367GSCDL
Pierce, L.E.	T34N R15W 07DDC1	Laclede	26139	01/01/1970	1306	129	85	6.25	72.10	––	15	––	367RBDX
Kelso, Junior	T34N R15W 07DDC2	Laclede	25745	01/01/1967	1312	330	21	6.25	239.10	01/01/1967	22	––	367GSCDL
Wilson, Clark	T34N R15W 07DDD1	Laclede	24749	01/01/1966	1305	362	20	6.25	241.00	01/01/1966	20	––	367GSCDL
Wallace, Cliff	T34N R15W 10CCC1	Laclede	––	01/01/1900	1230	320	200	6.25	200.00	01/01/1977	20	––	367GSCDL
Lewis, Tom	T34N R15W 10DDD1	Laclede	21347	01/01/1962	1181	120	32	6.25	55.70	01/01/1962	8	––	367RBDX
Sho Me Power Company	T34N R15W 13ABB1	Laclede	23739	01/01/1965	1122	165	40	6.25	55.00	01/01/1965	15	––	367GSCDU
Adamson, Burnis	T34N R15W 14ABA1	Laclede	26142	01/01/1968	1190	126	20	6.25	76.80	01/01/1968	36	––	367RBDX
Laclede PWSD3 No. 3	T34N R15W 17	Laclede	27166	01/01/1972	––	1280	––	––	––	––	400	––	371EMNC
Forgey, J.W.	T34N R15W 17DCC1	Laclede	22349	01/01/1963	1251	201	120	6.25	104.00	01/01/1963	28	––	367GSCDU
Peterson, Wayne	T34N R15W 18BAB1	Laclede	24378	01/01/1966	1300	300	80	6.25	210.10	01/01/1966	15	––	367GSCDL
Peterson, Wayne	T34N R15W 18BAB2	Laclede	26146	01/01/1968	1309	335	42	6.25	285.30	01/01/1968	15	––	367GSCDL
McCulloch, Albert	T34N R15W 18BCC1	Laclede	11017	01/01/1947	1290	200	40	6.25	137.00	01/01/1947	15	––	367GSCDU
Randolph, Russell	T34N R15W 19ABB1	Laclede	27099	01/01/1970	1262	210	47	6.25	121.20	01/01/1970	15	––	367GSCDL
Pruitt, Bob	T34N R15W 22DAD1	Laclede	21381	01/01/1962	1257	343	302	6.25	288.10	01/01/1962	21	0.7	367GSCDL
Wrinkle, Ken	T34N R15W 24ABA1	Laclede	13549	01/01/1955	1200	100	17	6.25	85.00	01/01/1955	16	––	367RBDX
Nethery, Marvin	T34N R15W 27BBB1	Laclede	13766	01/01/1955	1175	155	41	6.25	81.50	01/01/1955	4	––	367GSCDU
Thompson, Fay	T34N R15W 28CBC1	Laclede	23399	01/01/1965	1225	278	66	6.25	233.30	01/01/1965	8	––	367GSCDL
Mahan, Harold	T34N R15W 30CAC1	Laclede	27120	01/01/1970	1275	270	146	6.25	201.90	01/01/1970	23	––	367GSCDL
Caudle, Vernon	T34N R15W 30CBD1	Laclede	27175	01/01/1970	1275	286	90	6.25	221.20	01/01/1970	23	––	367GSCDL
Rubler, Edward	T34N R15W 33BDD1	Laclede	26162	01/01/1968	1235	195	43	6.25	100.00	01/01/1968	15	––	367GSCDL
Huff, Warren	T34N R15W 36DB	Laclede	20753	01/01/1961	1096	200	25	6.25	80.80	01/01/1961	25	––	367GSCDL
Laclede PWSD1 No. 2	T34N R16W 02BA	Laclede	25748	01/01/1967	1276	1150	630	8	327.30	01/01/1967	160	3.5	371POTS

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Reeves, Bob	T34N R16W 02BAA1	Laclede	24084	01/01/1965	1238	151	30	6.25	38.80	01/01/1965	0.5	—	368JFRC
Myers, Lee	T34N R16W 02BCA1	Laclede	13514	01/01/1955	1258	273	—	6.25	213.00	01/01/1955	12	—	367GSCDU
Shaddox, Rex	T34N R16W 02BCC1	Laclede	21502	01/01/1962	1279	301	38	6.25	203.70	01/01/1962	24	—	367GSCDU
Jayner, Fred	T34N R16W 02BDA1	Laclede	25073	01/01/1966	1260	102	39	6.25	24.00	01/01/1966	6	—	368JFRC
Baird Cleaners	T34N R16W 02CDD1	Laclede	13406	01/01/1955	1244	510	33	6.25	200.00	01/01/1955	75	—	367GNTR
Campbell, Jim	T34N R16W 03AD	Laclede	21083	01/01/1962	1243	260	30	6.25	161.70	01/01/1962	15	—	367GSCDU
Hamilton, C.L.	T34N R16W 03BC	Laclede	21724	01/01/1963	1202	253	55	6.25	179.70	01/01/1963	15	—	367GSCDL
Hall, Jim	T34N R16W 03BCD1	Laclede	21727	01/01/1962	1226	165	45	6.25	70.20	01/01/1962	25	—	367GSCDL
City of Lebanon, No. 4	T34N R16W 03DCB1	Laclede	9546	01/01/1947	1233	1637	533	6.25	345.10	01/01/1947	480	7.4	371POTS
Fitch, Avery	T34N R16W 05AAA1	Laclede	15869	01/01/1955	1157	209	77	6.25	128.70	01/01/1955	6	—	367GSCDL
Marks, Charles	T34N R16W 05DBC1	Laclede	15558	01/01/1955	1250	500	70	6.25	340.10	01/01/1955	14	—	371EMNC
Laclede PWSD #1	T34N R16W 06ADD1	Laclede	26570	08/01/1968	1262	1100	500	8	344.00	08/01/1968	235	—	367GNTR
Lebanon CC	T34N R16W 06DCA1	Laclede	12629	01/01/1957	1256	509	104	6.25	321.70	01/01/1957	20	—	371EMNC
Garner, Charles	T34N R16W 06DDA1	Laclede	15567	01/01/1955	1252	331	115	6.25	250.10	01/01/1955	16	—	367GSCDL
Young, John D.	T34N R16W 10CBB1	Laclede	23149	01/01/1964	1246	151	41	6.25	69.00	01/01/1964	21	—	367GSCDU
Lebanon #2	T34N R16W 10DBD1	Laclede	2224	08/16/1929	1260	1104	175	16	355.00	06/12/1952	450	—	367GNTR
Mid-Am Dairy	T34N R16W 10DC	Laclede	10159	01/01/1948	1238	1151	495	10	348.80	01/01/1948	260	4.3	371POTS
Frisco Railroad	T34N R16W 11BAC1	Laclede	7732	01/01/1942	1256	1151	500	12	345.00	01/01/1942	300	4.5	371POTS
City of Lebanon, No. 3	T34N R16W 11CAD1	Laclede	8041	01/01/1942	1278	1625	542	16	335.00	01/01/1942	495	3.3	371POTS
Boswell Stave Mill	T34N R16W 11DDD1	Laclede	4028	01/01/1936	1280	389	164	6.25	230.00	01/01/1936	—	—	367GSCD
Hyde, Myra	T34N R16W 13DBB1	Laclede	26138	01/01/1968	1280	211	146	6.25	99.20	01/01/1968	33	—	367GSCD
City of Lebanon, No. 5	T34N R16W 14ABB1	Laclede	27178	01/01/1972	1305	1760	556	13.40	383.20	01/01/1972	500	4.1	371POTS
Beard, W.C.	T34N R16W 16CCC1	Laclede	—	01/01/1962	1220	260	90	6.25	200.00	01/01/1977	10	—	367GSCD
Beard, W.C.	T34N R16W 20ABB1	Laclede	—	01/01/1962	1240	400	110	6.25	267.10	01/01/1977	10	—	367GSCDL
Compton	T34N R16W 24DCC1	Laclede	24383	01/01/1966	1285	305	74	6.25	255.20	01/01/1966	15	—	367GSCDL
Robnett, Wayne	T34N R16W 25BBB1	Laclede	23148	01/01/1964	1286	258	185	6.25	218.10	01/01/1964	15	—	367GSCDL
Lowe, Carl	T34N R16W 25DC	Laclede	24796	01/01/1966	1280	302	49	6.25	191.40	01/01/1966	—	—	367GSCDL
Collins, Paul	T34N R16W 26DAA1	Laclede	24377	01/01/1966	1295	215	46	6.25	163.40	01/01/1966	15	—	367GSCDL
Haymes, A.L.	T34N R16W 27BAC1	Laclede	10092	01/01/1948	1268	196	76	6.25	151.10	01/01/1948	16	—	367GSCDL
Maxey, Dean	T34N R16W 29BCC1	Laclede	—	01/01/1966	1290	165	20	6.25	49.40	01/01/1977	5	—	368CNDN
Garrett, Thomas	T34N R16W 33DBB1	Laclede	23145	01/01/1964	1325	271	100	6.25	175.00	01/01/1964	28	—	367GSCDL
Nelson, H.A.	T34N R17W 02DBB1	Laclede	—	01/01/1973	1265	340	120	6.25	229.20	01/01/1977	20	—	368CNDN
Myer, Henry	T34N R17W 06ADA1	Laclede	—	01/01/1962	1139	360	80	6.25	236.40	01/01/1977	10	—	368CNDN
Dismang, Dan	T34N R17W 10CDA1	Laclede	—	01/01/1960	1205	300	100	6.25	232.60	01/01/1977	20	—	368CNDN
J.E. Barber School	T34N R17W 12DDD1	Laclede	—	—	1286	400	—	6.25	340.10	01/01/1977	20	—	368CNDN
Marley, Lavone	T34N R17W 22BDA1	Laclede	—	01/01/1972	1229	200	70	6.25	70.10	01/01/1977	32	—	368CNDN
King, Ronald	T34N R17W 24DAA1	Laclede	—	01/01/1970	1320	500	100	6.25	256.10	01/01/1977	15	—	371CMBRU
Dame, Dale	T34N R17W 29ADA1	Laclede	—	01/01/1970	1250	255	80	6.25	80.00	01/01/1977	35	—	368CNDN
Romans, John	T34N R17W 36BAA1	Laclede	—	01/01/1969	1326	435	100	6.25	337.60	01/01/1977	20	—	371CMBRU
Offutt, Ross	T34N R18W 01ABB1	Dallas	23606	01/01/1965	990	281	44	6.25	120.30	01/01/1965	25	—	367GNTR
Meinen, Herman	T34N R18W 01ABB2	Dallas	23604	01/01/1965	987	272	41	6.25	125.90	01/01/1965	26	—	367GNTR
Cedar Courts	T34N R18W 01BAD1	Dallas	23737	01/01/1964	937	185	40	6.25	60.00	01/01/1964	12	—	367GSCDL
Smoot, David	T34N R18W 01DBB1	Adair	25451	01/01/1967	920	191	55	6.25	34.30	01/01/1967	35	—	367GNTR
Evan, E.M.	T34N R18W 01DCC1	Dallas	26713	01/01/1969	1143	229	49	6.25	120.20	—	—	—	367GSCDL
Camp Aurora	T34N R18W 03AAC1	Dallas	18164	01/01/1959	1021	300	—	—	—	—	30	—	367GSCDL
Dibbens, Lloyd	T34N R18W 06CBA1	Dallas	—	01/01/1955	1080	179	4	6.25	105.00	01/01/1977	15	—	368CNDN

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Phillips, Iver	T34N R18W 10BCA1	Dallas	—	01/01/1954	1120	180	40	6.25	139.00	01/01/1977	—	—	368CNDN
Oldham, Larry	T34N R18W 11AAD1	Dallas	—	01/01/1971	1120	580	240	6.25	241.30	01/01/1977	20	—	368CNDN
Hale, Levi	T34N R18W 18DCD1	Dallas	—	01/01/1900	1125	270	40	6.25	192.70	01/01/1977	15	—	368CNDN
Phillips, Otto	T34N R18W 21DAA1	Dallas	—	01/01/1956	1180	370	200	6.25	181.10	01/01/1977	15	—	368CNDN
Fireoved, Dale	T34N R18W 32BCD1	Dallas	15868	01/01/1955	1140	180	33	6.25	115.00	01/01/1955	9	—	367GSCDU
Long Lane School	T34N R18W 33DCD1	Dallas	13925	01/01/1955	1178	323	82	6.25	110.10	01/01/1955	25	—	367GSCDL
Krone, B.L.	T34N R19W 08CDA1	Dallas	8118	01/01/1942	1056	95	—	—	—	—	—	—	367GSCD
Douglas, Charles	T34N R19W 13CDD1	Dallas	—	01/01/1974	1120	230	56	6.25	68.10	01/01/1977	10	—	367GSCD
Grafton, H.R.	T34N R19W 33ABD1	Dallas	18127	01/01/1959	1142	268	15	6.25	145.10	01/01/1959	11	0.2	367RBDX
Jackson, Ralph	T34N R20W 11BCC1	Dallas	7487	01/01/1941	1168	135	18	5.60	70.00	01/01/1941	15	—	367RBDX
Grain, George F.	T34N R20W 14BDA1	Dallas	7488	01/01/1941	1145	152	50	6.25	66.00	01/01/1941	9	—	368JFRC
McQuire, Mickey	T34N R20W 15ABB1	Dallas	26320	01/01/1967	1102	240	75	6.25	100.10	01/01/1967	20	—	368JFRC
Buffalo #3	T34N R20W 26ABA1	Dallas	11219	02/10/1950	1192	1050	360	8	—	—	183	2.6	371POTS
Buffalo #2	T34N R20W 26ADB1	Dallas	8198	01/01/1955	—	1035	350	8	172.00	01/01/1955	45	0.3	371POTS
Williams, Claude	T34N R20W 26DCC1	Dallas	10209	01/01/1948	1197	285	30	5.60	95.20	01/01/1948	9	—	367RBDX
Peters, W.S.	T34N R20W 27ADC1	Dallas	—	01/01/1948	1177	135	13	5.60	58.00	01/01/1948	8	—	368JFRC
Wildwood Resort	T35N R14W 01ADB1	Laclede	11036	01/01/1949	981	165	52	6.25	80.10	01/01/1949	—	—	367GSCDU
Cliff Springs Camp	T35N R14W 09BAB1	Laclede	21332	01/01/1962	1009	450	225	6	140.30	01/01/1962	50	8.3	367GSCDU
Williams, Maude	T35N R14W 11CAB1	Laclede	23016	01/01/1964	966	260	66	6.25	110.40	01/01/1964	10	—	367GSCDL
Huizinga, William	T35N R14W 17CBA1	Laclede	—	01/01/1900	1100	204	60	6.25	154.00	01/01/1900	15	—	368CNDN
Builderback, Richard	T35N R15W 01DAD1	Laclede	23733	01/01/1965	1030	250	10	6.25	107.70	01/01/1965	20	—	368CNDN
Sullivan, James	T35N R15W 10ADD1	Laclede	23861	01/01/1965	1176	205	30	6.25	94.60	—	10	0.3	367RBDX
McMillen, Evan	T35N R15W 11CCC1	Laclede	23608	01/01/1965	1201	101	22	6.25	41.00	01/01/1965	44	—	368JFRC
Herndon, Chester	T35N R15W 16CCD1	Laclede	4188	01/01/1937	1205	365	63	6.60	189.00	01/01/1937	5	—	367GSCDL
Massey	T35N R15W 18CCC1	Laclede	11075	01/01/1947	1106	132	22	6.25	29.10	01/01/1947	7	—	367GSCDU
Sherrer, Ronald	T35N R15W 21BAA1	Laclede	23840	01/01/1965	1198	265	65	5	195.00	01/01/1965	12	—	367RBDX
Speaker, T.T.	T35N R15W 28BAA1	Laclede	23133	01/01/1964	1113	269	202	6.25	154.20	01/01/1964	26	—	367GSCDL
Mahan, Ruth	T35N R15W 31BD	Laclede	4411	01/01/1937	1200	165	32	6.25	56.00	01/01/1937	5	—	367RBDX
Vesta Courts	T35N R15W 32CDC1	Laclede	9245	01/01/1946	1260	571	253	5.60	175.30	01/01/1946	10	—	367GNTR
Vesta Courts	T35N R15W 32CDC2	Laclede	12407	01/01/1953	1278	295	104	6.25	169.70	01/01/1977	12	—	367GSCDU
Webb, Jay	T35N R15W 33BCD1	Laclede	26160	01/01/1975	1120	250	13	6.25	92.10	01/01/1975	12	—	367RBDX
Weaver, David	T35N R15W 36DAC1	Laclede	24380	01/01/1960	1225	153	23	6.25	95.20	01/01/1960	6	—	367RBDX
Williams, John	T35N R15W 36DCA1	Laclede	—	01/01/1972	1180	300	260	6.25	201.50	01/01/1972	20	—	368CNDN
Taylor, David	T35N R16W 01DD	Laclede	—	01/01/1975	1150	300	80	6.25	151.20	01/01/1977	32	—	368CNDN
Pullem, William	T35N R16W 03CDD1	Laclede	4349	01/01/1937	1170	241	52	6.25	195.00	01/01/1937	10	—	367GSCDL
Edmonds, Frank	T35N R16W 03DA	Laclede	9772	01/01/1946	1123	175	—	6.25	131.20	01/01/1946	5	—	367GSCDL
Bryant, L.H.	T35N R16W 10DAA1	Laclede	13515	01/01/1954	1178	240	190	6.25	171.10	01/01/1954	10	1.0	367GSCDL
Leblanc, George	T35N R16W 14BBB1	Laclede	24252	01/01/1966	1165	235	60	6.25	103.90	01/01/1966	12	—	367GSCDL
Capoterri, E.L.	T35N R16W 22DCD1	Laclede	—	01/01/1961	1203	405	155	6.25	360.00	01/01/1961	15	—	371EMNC
Klemin, Joe	T35N R16W 24DA	Laclede	13711	01/01/1955	1174	336	—	6.25	190.00	01/01/1955	20	—	367GSCDL
Fisher, Leonard	T35N R16W 24DAC1	Laclede	25264	01/01/1967	1178	300	116	6.25	165.50	01/01/1967	10	—	367GSCDL
Wrinkle, Delbert	T35N R16W 25ABA1	Laclede	21808	01/01/1963	1201	276	41	6.25	183.30	01/01/1963	22	—	367GSCDL
Truelove, Wayne	T35N R16W 27AAD1	Laclede	21344	01/01/1962	1185	380	126	6.25	226.10	01/01/1962	20	—	371EMNC
Brown, Bob	T35N R16W 29CAA1	Laclede	10894	04/01/1949	1187	182	71	6.25	173.00	04/01/1949	2	—	367GSCDL
Jakubowski, Frank	T35N R16W 35DCA1	Laclede	26112	01/01/1966	1220	205	55	6.25	160.00	01/01/1966	6	—	367RBDX

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Lee, Carl	T35N R17W 02BAC1	Laclede	24386	01/01/1965	1068	425	29	6.25	250.30	01/01/1965	15	—	367GSCDL
Parrott, J.W.	T35N R17W 03DDD1	Laclede	27181	01/01/1969	1080	281	54	6.25	221.00	01/01/1969	20	—	367GSCDL
Wiessengarber School	T35N R17W 11ADC1	Laclede	15559	01/01/1955	1048	302	33	6.25	200.20	01/01/1955	8	—	367GSCDL
Blattel, George	T35N R17W 11BBB1	Laclede	13755	01/01/1955	1080	330	28	6.25	250.40	01/01/1955	18	—	367GSCDL
Smith, James	T35N R17W 30BAD1	Laclede	15712	01/01/1956	889	177	19	6.25	34.90	01/01/1956	17	—	371EMNC
Missouri Park Board	T35N R17W 31BCC1	Laclede	23720	01/01/1965	878	600	250	8	14.80	01/01/1965	100	6.7	371POTS
Bennett Springs #1	T35N R17W 31CBD1	Laclede	23770	09/03/1965	884	600	250	8	16.00	09/03/1965	—	—	371EMNC
Bennett Spring Church Camp	T35N R18W 25CB	Dallas	6879	01/01/1941	1080	169	31	—	131.00	01/01/1941	12	—	367GSCDL
Burtin, Paul	T35N R18W 25DCD1	Dallas	23605	01/01/1965	909	210	41	6.25	61.30	01/01/1965	35	—	367GNTR
Blue, James	T35N R18W 32BAD1	Dallas	—	01/01/1968	1087	185	40	6.25	20.00	01/01/1968	15	—	368CNDN
Huber, Curtis	T35N R18W 33CDD1	Dallas	—	01/01/1974	1077	350	60	6.25	104.20	01/01/1977	15	—	368CNDN
Niangua Outdoor Recreation	T35N R18W 35BAB1	Dallas	20718	01/01/1962	974	350	254	6.60	105.10	01/01/1962	20	—	371EMNC
Alford, P.D.	T35N R19W 02CDD1	Dallas	10206	01/01/1948	1089	160	10	5.60	74.00	01/01/1948	4	—	367RBDX
Stone, Omie L.	T36N R13W 01BCA1	Pulaski	20224	01/01/1961	984	305	85	6.25	174.80	01/01/1961	12	—	367GSCDL
Smith, John L.	T36N R13W 01DDC1	Pulaski	13338	01/01/1955	956	215	—	6.25	214.90	01/01/1955	—	—	367GSCDL
Griffin, Jennie	T36N R13W 02ADB1	Pulaski	10808	01/01/1949	1020	225	41	6.25	175.00	01/01/1949	10	5.0	367GSCDL
Welch, E.S.	T36N R13W 02DBC1	Pulaski	16553	01/01/1957	999	300	43	6.26	185.00	01/01/1957	10	—	367GSCDL
Wall, Gene	T36N R13W 03BCA1	Pulaski	19489	01/01/1960	940	210	45	6.25	90.10	01/01/1960	12	—	367GSCDL
Wilson, Baker	T36N R13W 04BAD1	Pulaski	25367	01/01/1967	1024	205	46	6.25	125.00	01/01/1967	10	—	367GSCDU
Van Nardin, Carrie	T36N R13W 04CAD1	Pulaski	15634	01/01/1956	1022	185	59	6.25	135.00	01/01/1956	8	—	367GSCDU
Patrick, Ralph	T36N R13W 04CBC1	Pulaski	24790	01/01/1966	1141	325	113	6.25	224.70	01/01/1966	12	—	367GSCDU
Tomlinson, Fred	T36N R13W 05ADD1	Pulaski	21431	01/01/1962	1108	185	43	6.25	123.20	—	10	—	367RBDX
Johnson	T36N R13W 05CDD1	Pulaski	19799	01/01/1960	1117	220	150	6.25	150.00	01/01/1960	10	—	367RBDX
Patrick, Charles	T36N R13W 05DDA1	Pulaski	25374	01/01/1966	1108	180	101	6.25	100.40	01/01/1966	10	—	367RBDX
Richland #1	T36N R13W 07CCD1	Pulaski	17444	11/11/1930	1136	1170	—	—	252.00	01/01/1957	100	20.0	367GNTR
Miller, L.E.	T36N R13W 08CBC1	Pulaski	11948	01/01/1951	1119	175	100	6.25	99.90	01/01/1951	—	—	367RBDX
Richland #3	T36N R13W 08CBC2	Pulaski	27989	01/01/1976	1125	1225	450	10	263.00	01/01/1976	500	4.4	371POTS
Bohannon, Lynn	T36N R13W 08DAB1	Pulaski	13030	01/01/1954	1089	250	42	6.25	68.00	01/01/1954	27	0.4	367RBDX
Yourk, Earl	T36N R13W 08DBD1	Pulaski	18084	01/01/1959	1105	170	39	6.25	90.30	01/01/1959	7	0.2	367RBDX
Dipper, James	T36N R13W 08DBD2	Pulaski	19534	01/01/1960	1112	280	45	6.25	165.10	—	12	—	367RBDX
Craig, B.H.	T36N R13W 16AAA1	Pulaski	18939	01/01/1957	1011	240	—	6.25	180.10	01/01/1957	10	—	367GSCDL
Hathaway, Edgar	T36N R13W 16CBC1	Pulaski	10588	01/01/1948	1084	260	52	6.25	189.00	01/01/1948	7	—	367GSCDU
Miller, A.D.	T36N R13W 16CBC2	Pulaski	13032	01/01/1954	1085	340	91	6.25	288.20	01/01/1954	10	—	367GSCDL
Osborne, C.F.	T36N R13W 16CCA1	Pulaski	15035	01/01/1956	996	225	57	6.25	120.40	01/01/1956	7	—	367GSCDL
Richland #2	T36N R13W 18ABC1	Pulaski	9684	01/01/1947	1110	1202	335	8	240.00	01/01/1947	210	4.2	367GNTR
Bohannon, Lynn	T36N R13W 18CBC1	Pulaski	17903	01/01/1958	1107	436	50	6.25	220.30	01/01/1958	15	0.1	367GSCDL
Parsons, A.A.	T36N R13W 18DBC1	Pulaski	23046	01/01/1964	1082	340	41	6.25	210.00	01/01/1964	15	—	367GSCDU
Carnes, Burdette	T36N R13W 19BAA1	Pulaski	15036	01/01/1956	1071	170	38	6.25	75.00	01/01/1956	20	0.3	367RBDX
Trower, Bud	T36N R13W 19BCC1	Pulaski	20125	01/01/1961	1013	248	20	6.25	34.90	01/01/1961	30	—	367GSCDU
McDaniel, Orville	T36N R13W 30CAA1	Pulaski	22078	01/01/1963	951	275	—	6.25	100.00	01/01/1963	10	—	367GSCDL
Hansinger, John	T36N R13W 31DCB1	Pulaski	23047	—	932	320	43	6.25	90.40	01/01/1963	15	—	367GSCDL
Davis, Ishmael	T36N R14W 01BBB1	Camden	10586	01/01/1948	1035	90	29	6.25	55.00	01/01/1948	—	—	367RBDX
Shell Pipeline	T36N R14W 02CA	Camden	2126	01/01/1926	1102	800	—	—	150.00	01/01/1926	12	—	371EMNC
Wilson, Davis	T36N R14W 02ADA1	Camden	25292	01/01/1967	1064	280	33	6.25	189.80	01/01/1967	12	—	367GSCDU

Table 3 (continued)

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Schneider, Gordon	T36N R14W 02DCD1	Camden	13874	01/01/1955	1102	400	31	6.25	200.40	01/01/1955	20	—	367GSCDL
Remberton, Frank	T36N R14W 03CAD1	Camden	18887	01/01/1959	1014	225	38	6.25	139.90	01/01/1959	10	—	367GSCDL
Bollinger, Charles	T36N R14W 03DBD1	Camden	18886	01/01/1959	1002	85	27	6.25	50.00	01/01/1959	0.5	—	367RBDX
Ozark Fisheries	T36N R14W 06ABB1	Camden	15843	01/01/1957	892	975	—	—	52.70	01/01/1957	753	16.7	371POTS
Smith, Clarence	T36N R14W 08CDC1	Camden	17972	01/01/1959	982	130	22	6.25	100.30	01/01/1959	15	—	367RBDX
Moore, Herschel	T36N R14W 11DD	Camden	23275	01/01/1964	1050	390	43	6.25	155.70	01/01/1964	60	—	367GSCDL
Henry, Virgil	T36N R14W 11DDD1	Camden	15627	01/01/1956	1096	120	25	6.25	58.00	01/01/1956	10	—	368JFRC
Setser, Wayne	T36N R14W 12CCC1	Camden	22082	01/01/1963	1103	260	42	6.25	124.80	01/01/1963	10	—	367RBDX
York, Jesse	T36N R14W 12DCC1	Camden	19533	01/01/1960	1115	245	—	—	140.10	01/01/1960	10	—	367RBDX
Hammock, Wade	T36N R14W 13BAB1	Laclede	19536	01/01/1960	1114	—	41	6.25	209.90	01/01/1960	10	—	367GSCDU
Avery, Ebon	T36N R14W 13BBA1	Camden	15633	01/01/1956	1110	250	39	6.25	190.20	01/01/1956	13	—	367RBDX
Warden, J.A.	T36N R14W 13DDD1	Laclede	22098	01/01/1963	1112	330	42	6.25	190.30	01/01/1963	10	—	367GSCDU
Tuttle, Moses	T36N R14W 14BBA1	Camden	19491	01/01/1960	1038	220	36	6.25	150.20	01/01/1960	7	—	367GSCDU
Manes, Jerry	T36N R14W 21BCC1	Camden	20314	01/01/1961	1052	505	199	6.25	159.90	01/01/1961	20	—	367GNTR
Seay, Ralph	T36N R14W 22ABA1	Camden	17301	01/01/1958	1082	275	39	6.25	205.00	01/01/1958	10	—	367GSCDU
Zumalt, Bill	T36N R14W 24ACD1	Laclede	11034	01/01/1949	988	140	29	6.25	80.00	01/01/1949	—	—	367RBDX
Smith, Norman	T36N R14W 24ADA1	Laclede	23829	01/01/1965	1028	215	58	6.25	145.00	01/01/1965	40	—	367GSCDU
Johnson, Cecil	T36N R14W 25BBD1	Laclede	12075	01/01/1951	971	135	25	6.25	79.80	01/01/1951	—	—	367RBDX
Eureka Church	T36N R14W 25CBB1	Laclede	11967	01/01/1951	998	125	13	6.25	60.00	01/01/1951	—	—	367RBDX
Ogle, Junie	T36N R14W 26BCA1	Laclede	11965	01/01/1951	1018	95	38	6.25	25.00	01/01/1951	—	—	367RBDX
Bell, Merl	T36N R14W 31ABC1	Laclede	24080	01/01/1965	1166	375	42	6.25	251.50	01/01/1965	22	—	367GSCDL
Laclede PWSD #2	T36N R14W 31ACB1	Laclede	25771	08/01/1968	1165	1235	350	12	263.00	08/01/1968	65	1.0	367GNTR
Williams, Ray	T36N R14W 35ACC1	Laclede	24225	01/01/1966	1002	245	85	6.25	133.80	01/01/1966	25	—	367GSCDL
Ozark Fisheries	T36N R15W 01DAC1	Camden	—	01/01/1958	900	932	—	—	75.00	01/01/1958	—	—	371CMBRU
Scrivner, W.P.	T36N R15W 07ABC1	Laclede	21345	01/01/1962	1133	390	47	6.25	297.40	01/01/1962	15	—	371EMNC
Curl, Edward	T36N R15W 07CBC1	Laclede	13519	01/01/1954	1086	150	46	6.25	124.50	01/01/1954	5	—	367GSCDU
Webster, Charles	T36N R15W 11CBD1	Laclede	—	01/01/1976	1005	265	—	—	112.80	01/01/1977	—	—	—
Malin, Robert	T36N R15W 17DCC1	Laclede	23308	01/01/1964	1171	300	90	6.25	214.70	01/01/1964	12	—	367GSCDL
Sherrer, A.L.	T36N R15W 18AAB1	Laclede	23839	01/01/1965	1125	290	73	6.25	171.30	01/01/1965	10	—	367GSCDL
Newell, Ralph	T36N R15W 28DAD1	Laclede	—	01/01/1971	1145	210	91	6.25	147.80	01/01/1977	13	—	367GSCD
Rockhill, Howard	T36N R15W 31CBC1	Laclede	23395	01/01/1965	1110	250	17	6.25	147.50	01/01/1965	22	—	367GSCDL
Buschman, B.W.	T36N R16W 13BBD1	Laclede	24351	01/01/1966	1016	250	185	6.25	135.10	01/01/1966	25	—	367GSCDL
Wassem, Roger	T36N R16W 21DDC1	Laclede	24081	01/01/1965	1129	400	71	6.25	219.50	01/01/1965	20	—	367GNTR
George, Archie	T36N R16W 23AAA1	Laclede	13518	01/01/1954	1020	268	21	6.25	125.00	01/01/1954	10	0.4	367GSCDL
Missouri Highway Dept.	T36N R16W 28ADA1	Laclede	21363	01/01/1962	1112	350	—	6.25	208.00	01/01/1962	—	—	367GSCDL
Schmalstig, James	T36N R17W 03ABC1	Laclede	—	01/01/1973	1020	340	100	6.25	260.10	01/01/1977	10	—	367GNTR
Haan, Albert E.	T36N R17W 24DA	Laclede	—	01/01/1974	1160	330	300	6.25	160.00	01/01/1977	20	—	367GSCDL
Summers, J.H.	T36N R17W 30BAB1	Laclede	4947	01/01/1938	980	131	29	6.25	88.00	01/01/1938	—	—	367GSCDL
Bassore, George	T36N R17W 30DAB1	Laclede	4901	01/01/1938	820	130	17	6.25	—	—	—	—	371EMNC
Hornick, R.E.	T36N R17W 35CCC1	Laclede	13764	01/01/1955	1038	250	20	6.25	198.30	01/01/1955	8	—	367GSCD
Hurst, Earl	T36N R18W 10BCC1	Dallas	15908	01/01/1957	793	85	17	6.25	14.00	01/01/1957	5	—	367GNTR
Adams, Fred	T36N R18W 31BA	Dallas	17881	01/01/1958	1025	555	—	—	90.00	01/01/1958	1140	51.8	371EMNC
Becker, Clyde	T37N R13W 04ACA1	Pulaski	19487	01/01/1960	1082	167	43	6.25	65.00	01/01/1960	10	—	368JFRC
Thornsberry, C.E.	T37N R13W 06ADD1	Pulaski	18165	01/01/1959	963	295	9	6.25	70.00	01/01/1959	8	—	367GSCDL
Glackin, Hugh	T37N R13W 07BCB1	Pulaski	13421	01/01/1954	1017	235	43	6.25	125.10	01/01/1954	15	—	367GSCDU

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Groce, Lee	T37N R13W 08CBD1	Pulaski	15030	01/01/1956	1100	335	32	6.25	220.40	01/01/1956	15	—	367GSCDU
Tomlin, Don	T37N R13W 09ADD1	Pulaski	22079	01/01/1963	1122	140	47	6.25	60.20	01/01/1963	15	—	368JFRC
Wadell, Roy	T37N R13W 09BDB1	Pulaski	18618	01/01/1959	1038	125	22	6.25	40.00	01/01/1959	2	—	368JFRC
Roam, Ferrell	T37N R13W 09DAB1	Pulaski	25373	01/01/1966	1128	225	38	6.25	119.80	01/01/1966	10	—	368JFRC
Roam, H.J.	T37N R13W 15BDB1	Pulaski	16567	01/01/1957	1035	315	22	6.25	209.60	01/01/1957	15	—	367GSCDL
Crumeley, M.	T37N R13W 15DAD1	Pulaski	11729	01/01/1950	1015	135	26	6.25	40.00	01/01/1950	—	—	368JFRC
Crumeley, Joe	T37N R13W 15DAD2	Pulaski	19800	01/01/1961	1027	240	60	6.25	100.00	01/01/1961	10	—	367RBDX
Strom, Norm	T37N R13W 16BCB1	Pulaski	11731	01/01/1950	1162	165	41	6.25	90.30	01/01/1950	—	—	368JFRC
Black, J.R.	T37N R13W 21BDC1	Pulaski	17963	01/01/1959	1130	250	39	6.25	160.10	01/01/1959	8	—	367RBDX
Black, J.R.	T37N R13W 21DBD1	Pulaski	11970	01/01/1948	1083	170	19	6.25	94.90	01/01/1948	—	—	367RBDX
Thornsberry, Robert	T37N R13W 22AAB1	Pulaski	15039	01/01/1956	1040	140	87	6.25	60.20	01/01/1956	20	—	368JFRC
Day, W.C.	T37N R13W 22CAC1	Pulaski	—	01/01/1953	1171	183	29	6.25	74.90	01/01/1953	15	—	367RBDX
Larson, C.H.	T37N R13W 27BAA1	Pulaski	16895	01/01/1957	1173	250	54	6.25	70.00	01/01/1957	10	—	367RBDX
Davis, James	T37N R13W 28CB	Pulaski	16570	01/01/1957	1169	305	33	6.25	249.60	01/01/1957	10	—	367GSCDU
McDaniel, K.	T37N R13W 28CBB1	Pulaski	23043	01/01/1964	1194	323	42	6.25	215.40	01/01/1964	10	—	367GSCDU
Sears, F.E.	T37N R13W 29CAD1	Pulaski	15625	01/01/1956	1180	345	28	6.25	220.30	01/01/1956	15	—	367RBDX
Shell Pipeline	T37N R13W 29DBA1	Pulaski	11515	01/01/1951	1165	905	—	—	330.00	01/01/1951	—	—	371EMNC
McMucker, Charles	T37N R13W 33AAD1	Pulaski	10814	01/01/1949	986	130	19	6.25	25.00	01/01/1949	—	—	367GSCDU
Thomas, Chester	T37N R13W 33DDB1	Pulaski	11288	01/01/1949	953	75	25	6.25	30.00	01/01/1949	—	—	367RBDX
McMucker, Charles	T37N R13W 34BDD1	Pulaski	10816	01/01/1949	1020	175	19	6.25	75.00	01/01/1949	—	—	367GSCDU
Leadbetter, Ward	T37N R13W 34BDD2	Pulaski	15222	01/01/1951	1039	260	23	6.25	110.30	01/01/1951	10	—	367GSCDL
Leadbetter, Omar	T37N R13W 35ACD1	Pulaski	25251	01/01/1967	1009	215	120	6.25	160.10	01/01/1967	8	—	367GSCDL
Davis, Avery	T37N R13W 35ADB1	Pulaski	25365	01/01/1967	1004	235	40	6.25	159.70	01/01/1967	10	—	367GSCDL
Eckman, Ethel	T37N R13W 35CAD1	Pulaski	15219	01/01/1956	994	225	38	6.25	126.00	01/01/1956	10	—	367GSCDL
Kissinger, Cleve	T37N R13W 35CBB1	Pulaski	16555	01/01/1957	973	210	44	6.25	120.40	01/01/1957	15	—	367GSCDL
Jennings, Fred	T37N R13W 35DAB1	Pulaski	13426	01/01/1955	1025	250	43	6.25	169.90	01/01/1955	8	—	367GSCDL
Pollreisz, John	T37N R14W 05DDC1	Camden	—	01/01/1900	970	180	37	6.25	35.20	01/01/1977	10	—	368CNDN
Deberry, Walter	T37N R14W 23CAA1	Pulaski	—	01/01/1968	980	300	151	6.25	92.00	01/01/1968	25	—	367GSCDL
Campbell, Donald	T37N R14W 24ACD1	Camden	17970	01/01/1959	915	64	13	6.25	30.00	01/01/1959	4	—	367RBDX
Ozark Fisheries	T37N R14W 30DDA1	Camden	19598	01/01/1959	820	952	—	—	35.30	01/01/1977	—	—	371POTS
Ozark Fisheries	T37N R14W 31CAA1	Camden	19496	01/01/1960	869	957	—	—	—	—	—	—	371POTS
Carroll, Doral	T37N R14W 32CDB1	Camden	13861	01/01/1955	988	115	14	8	80.00	01/01/1955	5	—	367RBDX
Noe, Marion	T37N R14W 35AAD1	Camden	21472	01/01/1962	880	160	43	6.25	50.20	01/01/1962	20	—	367GSCDL
Bowles, Jim	T37N R14W 36AAD1	Camden	12073	01/01/1952	972	130	45	6.25	80.00	01/01/1952	—	—	367RBDX
Stormer, W.J.	T37N R14W 36ACC1	Camden	13996	01/01/1955	908	100	32	6.25	16.00	01/01/1955	15	—	367GSCDU
Hines, Richard	T37N R15W 06DB	Camden	7813	01/01/1942	1052	380	37	6.25	76.00	01/01/1942	—	—	367GSCDL
Pierce, D.	T37N R15W 20AAD1	Camden	—	01/01/1974	1080	282	80	6.25	180.30	01/01/1977	—	—	367GSCDL
Ozark Fisheries	T37N R15W 23BD	Camden	23050	01/01/1964	985	265	42	6.25	136.00	01/01/1964	15	—	367GSCDL
Ozark Fisheries	T37N R15W 23CD	Camden	23045	01/01/1964	884	255	21	6.25	54.00	01/01/1964	15	—	367GSCDL
Ozark Fisheries	T37N R15W 25BDA1	Camden	22579	01/01/1964	825	925	—	—	10.60	01/01/1964	660	5.8	371POTS
Ozark Fisheries	T37N R15W 25CAA1	Camden	4772	01/01/1938	870	77	—	—	20.00	01/01/1938	—	—	367GSCDU
Ozark Fisheries	T37N R15W 25CCA1	Camden	4766	—	900	193	69	6.25	45.10	01/01/1938	—	—	367GSCDL
Oursbourn, Lynn	T37N R15W 32DBA1	Camden	4444	01/01/1937	1090	144	60	6.25	78.20	01/01/1937	—	—	367GSCDL
Camden PWSD2, Well #2	T37N R16W 04BDD1	Camden	27880	01/01/1974	1050	848	330	—	271.20	01/01/1974	120	—	371EMNC
Chandler, Mack	T37N R16W 07DA	Camden	13462	01/01/1955	1065	275	66	6.25	225.00	01/01/1955	5	—	367GSCDL

Table 3 (continued)

Owner	Local number	County	DNR-DGLS log number	Date completed	Altitude of land surface (feet)	Depth of well (feet)	Depth cased (feet)	Casing diameter (inches)	Water level (feet)	Date water level measured	Discharge (gallons per minute)	Specific capacity	Principal aquifer
Ward, Clyde	T37N R16W 08DDC1	Camden	20374	01/01/1962	1104	345	80	6.25	200.30	01/01/1962	15	---	367GSCDL
Leffert, Ken	T37N R16W 26ABB1	Camden	---	01/01/1975	980	401	80	6.25	200.00	01/01/1977	55	---	367GNTR
Wollander, Ken	T37N R16W 30BC	Camden	---	01/01/1971	1020	400	---	6.25	238.10	01/01/1977	20	---	367GNTR
Barton, Bob	T37N R16W 34ADD1	Camden	---	01/01/1973	1040	425	200	6.25	150.30	01/01/1977	25	---	367GNTR
Mozark Club	T37N R17W 07AD	Camden	2678	01/01/1932	745	225	---	6.25	75.00	01/01/1932	---	---	371EMNC
Stewart, James	T37N R17W 16DB	Camden	27908	01/01/1975	900	300	165	6.25	120.40	01/01/1975	20	---	371EMNC
Moore, Del	T37N R18W 25CBB1	Camden	---	01/01/1966	730	100	---	6.25	40.00	01/01/1977	15	---	371EMNC
Seaton, Elbert	T37N R19W 35DBA1	Camden	15966	01/01/1956	1121	100	81.	6.25	67.00	01/01/1956	10	---	367RBDX
Ravenscroft, E.R.	T38N R13W 30ABA1	Pulaski	22084	01/01/1963	1094	280	50	6.25	170.30	01/01/1963	15	0.4	367RBDX
Zeigenbein, Charles	T38N R14W 07BBC1	Miller	---	01/01/1963	750	220	---	---	70.60	01/01/1977	---	---	371CMBRU
Moneymaker, Wayne	T38N R14W 13ABC1	Miller	---	01/01/1976	1020	280	80	6.25	130.00	01/01/1977	10	---	368CNDN
Hopkins, Ogle	T38N R14W 20BAB1	Camden	---	01/01/1969	720	400	---	---	15.20	01/01/1969	15	---	371CMBRU
Winfrey, Bob	T38N R14W 31BAA1	Camden	---	01/01/1973	820	265	80	6.25	185.20	01/01/1977	---	---	368CNDN
Davis, William L.	T38N R14W 32ACD1	Camden	---	01/01/1964	910	188	144	6.25	76.00	01/01/1964	---	---	368CNDN
McCubbens State Park	T38N R15W 05ABC1	Camden	26586	01/01/1970	842	550	365	6	133.20	01/01/1970	100	---	371EMNC
Ungard	T38N R15W 09BC	Camden	6564	01/01/1940	879	110	---	---	60.00	01/01/1940	---	---	367RBDX
George, Jerry	T38N R15W 14CDC1	Camden	---	01/01/1970	750	1200	26	8	15.20	01/01/1977	---	---	371CMBRU
Franklin, J.C.	T38N R15W 18BAB1	Camden	---	01/01/1976	880	255	---	---	151.00	01/01/1977	6	---	368CNDN
Franklin, Clarence	T38N R15W 18BCC1	Camden	---	01/01/1952	860	170	---	---	90.20	01/01/1977	15	---	368CNDN
George, Nobel	T38N R15W 23BBA1	Camden	---	01/01/1950	822	---	---	---	70.40	01/01/1977	4	---	368CNDN
St Moritz	T38N R16W 17ACB1	Camden	27342	01/01/1973	800	540	400	6.25	149.80	01/01/1973	75	---	371EMNC
Heritage	T38N R16W 22ABC1	Camden	---	01/01/1975	908	400	---	6.25	113.20	01/01/1977	40	---	367GNTR
Dillenberger, W.F.	T38N R17W 31ADB1	Camden	13599	01/01/1955	989	210	35	6.25	52.00	01/01/1955	---	---	367GSCDL
Lake Valley CC	T38N R17W 33DBD1	Camden	25162	01/01/1967	764	550	250	6	78.30	01/01/1967	93	1.2	371POTS
Gilliam, Gene	T39N R14W 27AB	Miller	18913	01/01/1959	970	165	23	6.25	100.00	01/01/1959	15	---	367RBDX

Figure 13 (in pocket) was constructed using an average water-level depth of 150 ft. When compiling the map, great care was necessary to avoid including water levels from more than one aquifer.

The shallowest water levels were mostly obtained from wells in valleys; the deepest, from those on or near hills. All four potentiometric surfaces are not present in all areas; in most there are only two or three. In some areas, such as in the upper part of the Goodwin Hollow drainage basin just west of Lebanon, only the deepest zone is generally present.

Groundwater in all the aquifers constantly moves from areas of high head to areas of low head. The potentiometric surfaces have gradients toward points of discharge: seeps and small-volume springs along hillsides or in small tributary valleys, and high-volume springs in the large valleys. The potentiometric surface illustrated in figure 13 (in pocket) is locally influenced by structure associated with major surface drainage, and by large fault systems.

The multiple water-level phenomenon and the relation of stratigraphy and geologic structure to water levels in the study area are illustrated in figure 16, a west-to-east hydrogeologic cross section through the center of the study area.

Sokolov (1967), in describing a similar multiple system, termed the higher levels "suspended" karst waters. He believes the main control upon such waters is nonuniform permeability of the rock and the local presence of impermeable zones, and that the most favorable conditions for a multiple system are in uplifted areas with moist climates.

Because of the predominance of carbonates, openings along bedding planes and fractures have been enlarged by moderate to intense dissolution. Burdon (1967) believes that fissure enlargement is predominantly vertical above the zone of saturation and horizontal below it. Based on water-well records, inflows of water often occur when a bedding plane or other horizontal opening is penetrated after drilling dry through massive rock to a considerable depth below the potentiometric surface. On the other hand, connection through vertical openings between shallow and deep zones is shown during pump tests, by the declining rate in lowering of the water level in a deep well when the drawdown data are plotted semi-logarithmically, indicating drainage from overlying beds to the principal aquifer open to the well.

Permeability produced by erosional unloading and consequent solution along bedding planes is probably much more important than previously recognized. Snow (1968) believes that opening and closing of these smaller horizontal features in response to the "breathing" effect of fluid-pressure reversals or changes is very important in increasing permeabilities. He discovered horizontal permeability increased with pressure faster than vertical permeability. In general, solution channels provide relatively open, if not direct, conduits for water movement.

Significant local recharge to the system is proved by differences in head between the various aquifers. Observation-well records (fig. 17) in the Lebanon area indicate a fairly rapid water-level response to local rainfall. Water levels in wells completed in the shallow aquifers ("50-foot" and "100-foot" water-level zones) have been reported to rise within hours of substantial local rainfall.

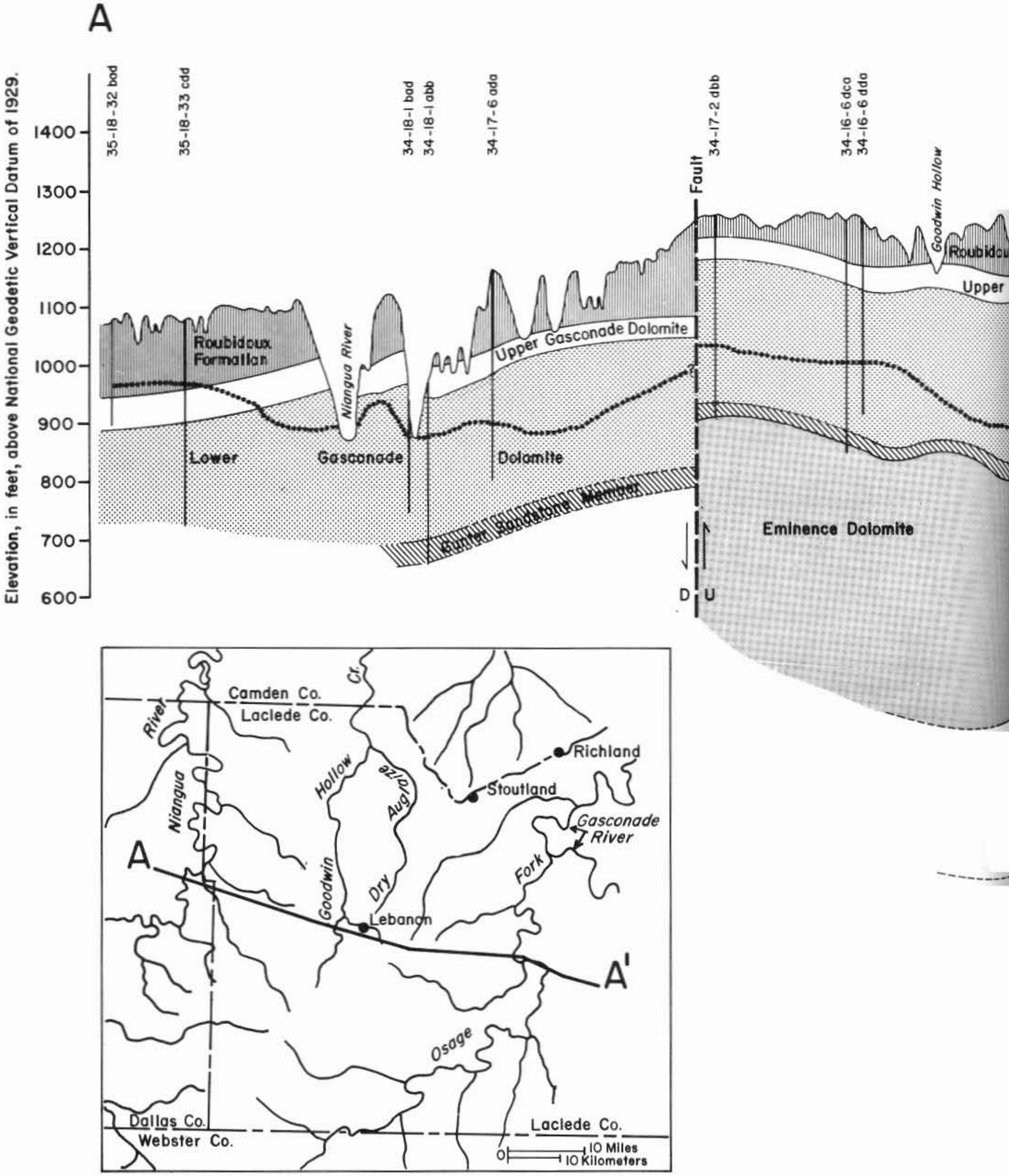
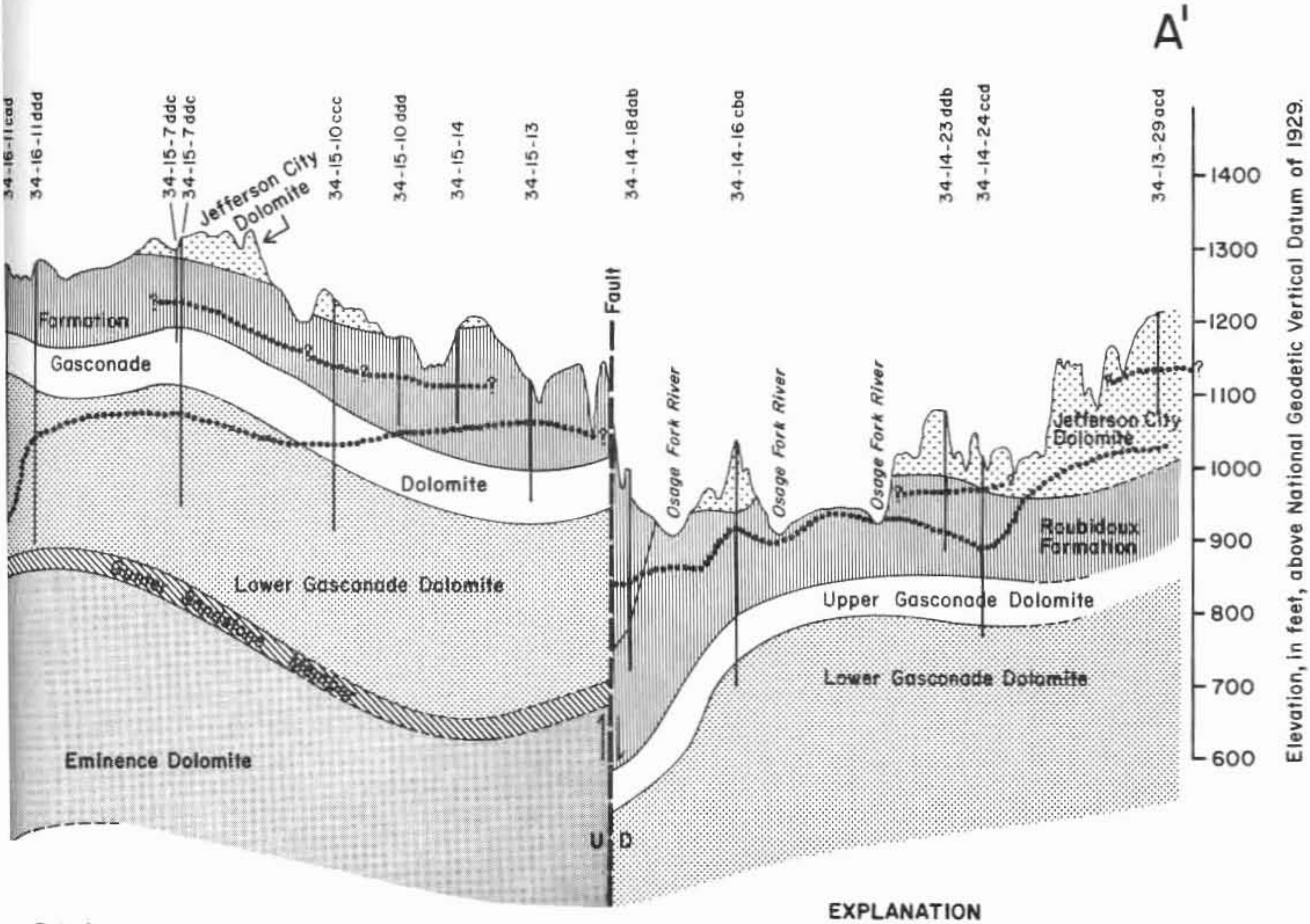


Figure 16. Hydrogeologic section showing multiple water levels and structure.



Potosi Dolomite

Derby - Doe Run Dolomite and Davis Formation

Bonneterre Formation

Lamotte Sandstone

EXPLANATION

Water level.

34-16-6dca

Control well. Numbers indicate location (see Table 3).

1 0 1 2 3 Miles

1 0 1 2 3 Kilometers

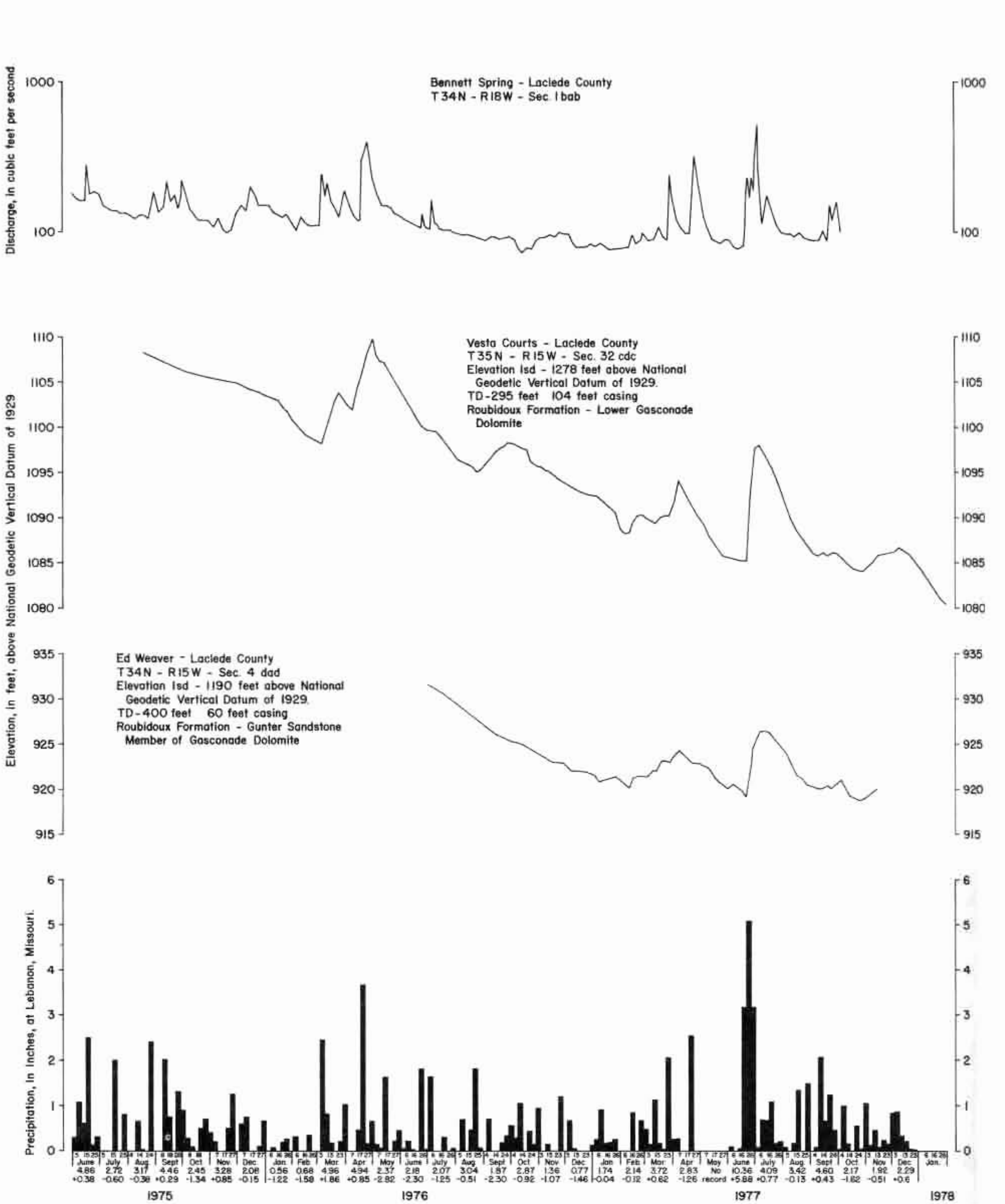


Figure 17. Hydrographs of selected observation wells, compared to discharge of Bennett Spring and precipitation at Lebanon.

The drought that affected groundwater levels during the current study altered expected seasonal trends. Long-term observation wells in other parts of the Ozark carbonate region show seasonal fluctuations of water levels, partly resulting from evapotranspiration, with highs in March or April and lows in October or November. Water levels in the study area, however, maintained a downward trend during the investigation. Normal, or above normal, rainfall during the last year of this study (1977) did not reverse the downward trend of groundwater levels, but it did prevent much lower water levels.

Water levels recovered during the last part of June 1977 (fig. 17). Significant rainfall occurred during the following months, and water levels declined, but did not reach the downward trends established earlier in the year. This indicates a rather rapid movement of recharge water through large near-surface conduits, with no significant recharge of the small-diameter network.

The total volume of rainfall in a karst area such as this is not as important to recharge as the distribution, both spatially and chronologically, because the distribution controls the percentage of annual infiltration (Kessler, 1967). The amount of infiltration or recharge is not directly proportional to the amount of yearly rainfall and may vary in the same area by an order of magnitude (Kessler, 1958).

Recharge occurs in upland interstream areas by infiltration of water into residual material, then into bedrock. This direct infiltration can be termed "diffuse circulation"; it enlarges joints by dissolution (Burdon, 1967). The amount of infiltration in upland areas depends on soil types and topographic setting (Reesman and others, 1975). Gentle slopes favor increased infiltration; steeper slopes, increased runoff and less diffuse infiltration.

The system is rapidly recharged through stream losses and through conduits in upland sinkholes. This type of recharge, called "concentrated circulation" by Burdon, is illustrated by the recharge in the Goodwin Hollow area.

Although much recharged water is rapidly flushed through the shallow part of the system during a rainy period, a significant amount penetrates to greater depths. This is illustrated in figure 17. After heavy rain in June 1977, the water level in the Weaver well rose conspicuously, a significant reversal of the steep downward trend that ended in June. The Vestal Courts well showed a larger immediate rise, but it also declined to a level closer to that reached during the previous downward trend than did the water level in the Weaver well. In addition, the discharge of Bennett Spring (plate 12) increased significantly by an amount commensurate with the rise in the Weaver well, suggesting that recharge to the entire system is significant, because the long-term flow characteristics of Bennett Spring depend on the water available from the entire system.

Fluctuations of water levels in all these artesian aquifers result from events such as alternating periods with and without rainfall, and alternating periods of pumping and nonpumping of nearby wells. Every drop of water recharged to the system tends to increase the head throughout the system. In some instances, in response to recharge, water levels rise in wells that are miles from recharge areas.

Fluctuations in water levels are more pronounced and of shorter duration in the shallow, less productive aquifers

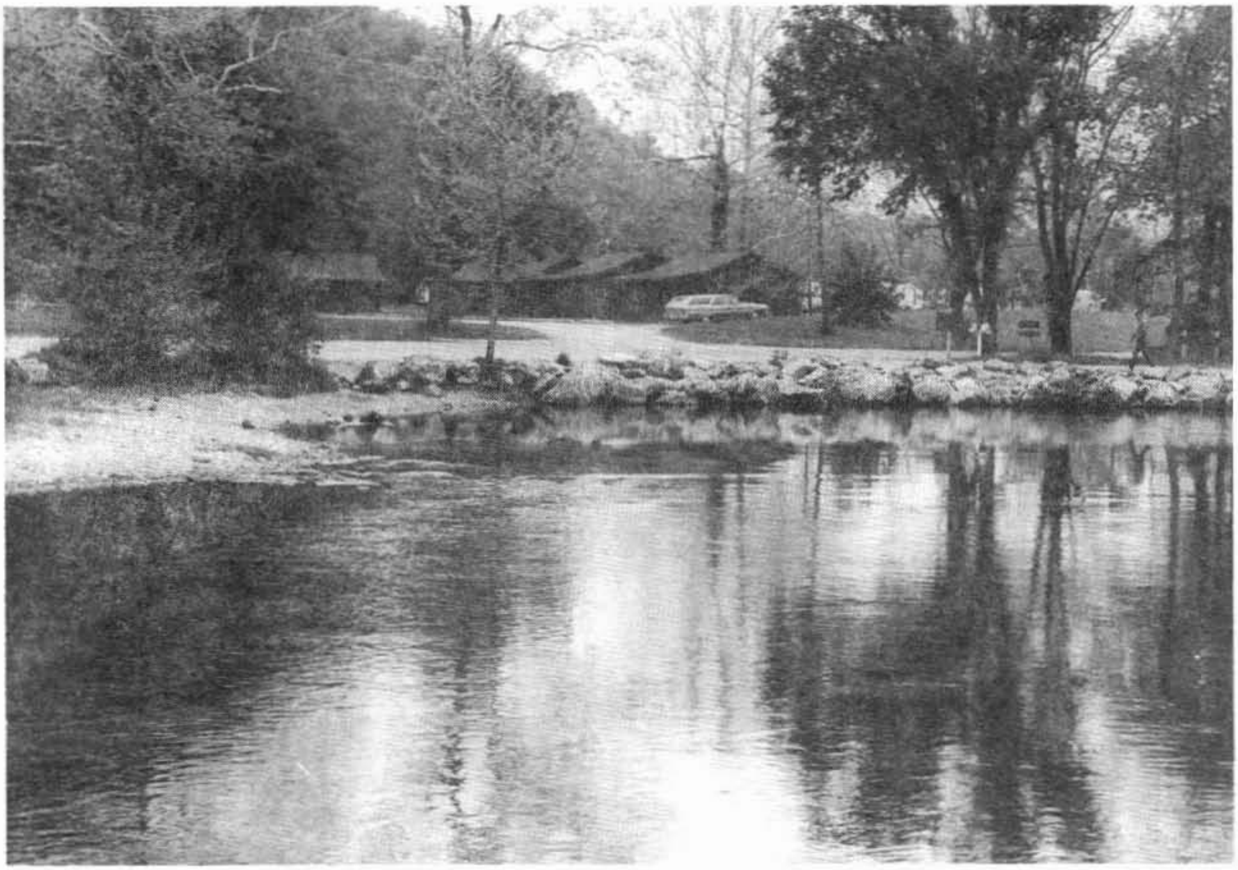


Plate 12A. View of Bennett Spring, looking southwest across the spring pool. Photograph by James E. Vandike.

than in the deeper, high-yield aquifers (fig. 17). Proximity to the land surface is the primary reason why shallow aquifers show greater water-level fluctuations than the deeper aquifers. The deeper are primarily recharged by water movement through shallow zones, so response to precipitation is usually slower but more sustained than in shallow aquifers.

At depth, seasonal fluctuations are usually smaller in areas with multiple aquifers than in those having direct recharge to deeper, high-yield aquifers (Sokolov, 1967).

A true artesian hydrologic system is impossible under physical conditions like those in the study area. Rather, all phases from true water-table conditions to (but not including) true artesian conditions probably exist somewhere in the study area.

In the previous discussion of karst recharge and flow mechanisms, two important aspects deserving further discussion were not mentioned: the rate of flow through the medium, and the chemical character of the water moving through the rock. During periods when the system is full after extended

Plate 12B. Aerial view of Bennett Spring; south is at the top. The spring pool is visible as a circular feature in the stream, just left of the central upper part of the photo. Photograph by James E. Vandike.

rainfall, flow is at a maximum, and in the large conduits it is turbulent. At these times the concentration of calcium carbonate in the water is low. Such conditions contribute to increasing permeability by solution. After initial flushing, residence time of water in the system is comparatively long, calcium carbonate concentration is more nearly in equilibrium, and the rate of solution of material is reduced. Thrailkill (1968), however, states that even though water introduced by diffuse infiltration may become calcium carbonate saturated after movement through residual soils and small secondary rock openings, undersaturation of the water can result from the increased pressure at depth, mixing of waters of different composition, and changes in the rate of flow. Surface water is undersaturated, and when it is introduced into the system through losing streams, solution of carbonate material is facilitated.

Caves are common in the area, but these large conduits probably transport only a relatively small percentage of the total underground flow. Mijatovic (1968) indicates that spring discharges and well hydrographs in carbonates show three distinct stages following periods of

precipitation. The initial stage is when spring discharge begins to recede, and well hydrographs show a rapid decline, a stage that represents drainage in the large conduits (3 ft or more in width). The second stage comprises a longer decline in spring discharge and a less steep lowering on the well hydrograph, a stage that represents drainage in the numerous water-bearing cracks and crevices (approximately 4 in. wide). The final stage represents prolonged drainage in very small openings (less than 0.5 in. wide), a stage characterized by sustained and relatively stable springflow and moderate to very slight lowering of water levels in wells. The prolonged recession indicates that these very small openings contain many times the storage capacity of the larger conduits. Although masked somewhat by drought conditions and by intermittent rainfall, these stages are discernible on hydrographs of observation wells measured during this study (fig. 17).

A semilogarithmic plot of water-level elevations versus well depths in the vicinity of Lebanon, Richland, and Bennett Spring (fig. 18) shows that, in the Lebanon and Richland areas, water-level elevations decline with increasing well depth, and that, at Bennett Spring, they rise slightly as well depths increase.

At Richland and Lebanon, shallow wells are completed in the Jefferson City Dolomite and Roubidoux Formation; deep wells, in the Lower Gasconade, Eminence, and Potosi Dolomites. At Bennett Spring, shallow wells are completed in the Gasconade Dolomite; deep wells, in the Potosi Dolomite. Richland and Lebanon were selected for comparison with Bennett Spring, because they are the only places where a sufficiently large cluster of wells exists near a divide to warrant analysis.

The data plot for the wells in the vicinity of Richland shows that water-level elevations do not decline significantly below a depth of about 400 ft. In contrast, the data plot for the wells in the vicinity of Lebanon shows that water levels decline with deeper drilling.

At Bennett Spring, the rising water-level trend in wells indicates they are in a discharge area and also suggests that vertical permeability along fractures results in equalization of water levels. Friction loss as the water rises to the surface along fractures from a depth of 600 ft may also be a cause of the gently rising trend at Bennett Spring, compared to the steeper trends at Lebanon and Richland. The steep trend of water-level elevations in the vicinity of Lebanon would seem to indicate poorer vertical permeability between deep aquifers in a recharge area, because a change in trend like that at Richland is not evident. The authors do not believe that the trend at Lebanon is due to pumpage in that area, because modern (1972) water levels in the Lebanon area are comparable to historical (1887-1947) data (Searight, 1955). The steep, uniform trend at Lebanon may be due to lowering of water levels in deep aquifers, by discharge along the Niangua River. If Bennett Spring and the Niangua River did not exist, perhaps water levels in deep and shallow wells at Lebanon would have the same relation to each other that they have at Richland. No large natural discharge of water commensurate with that on the Niangua River exists near Richland.

As indicated by the scarcity of shallow wells and the need to drill deeper to obtain water, vertical permeability increases west of Lebanon, between Goodwin Hollow and the

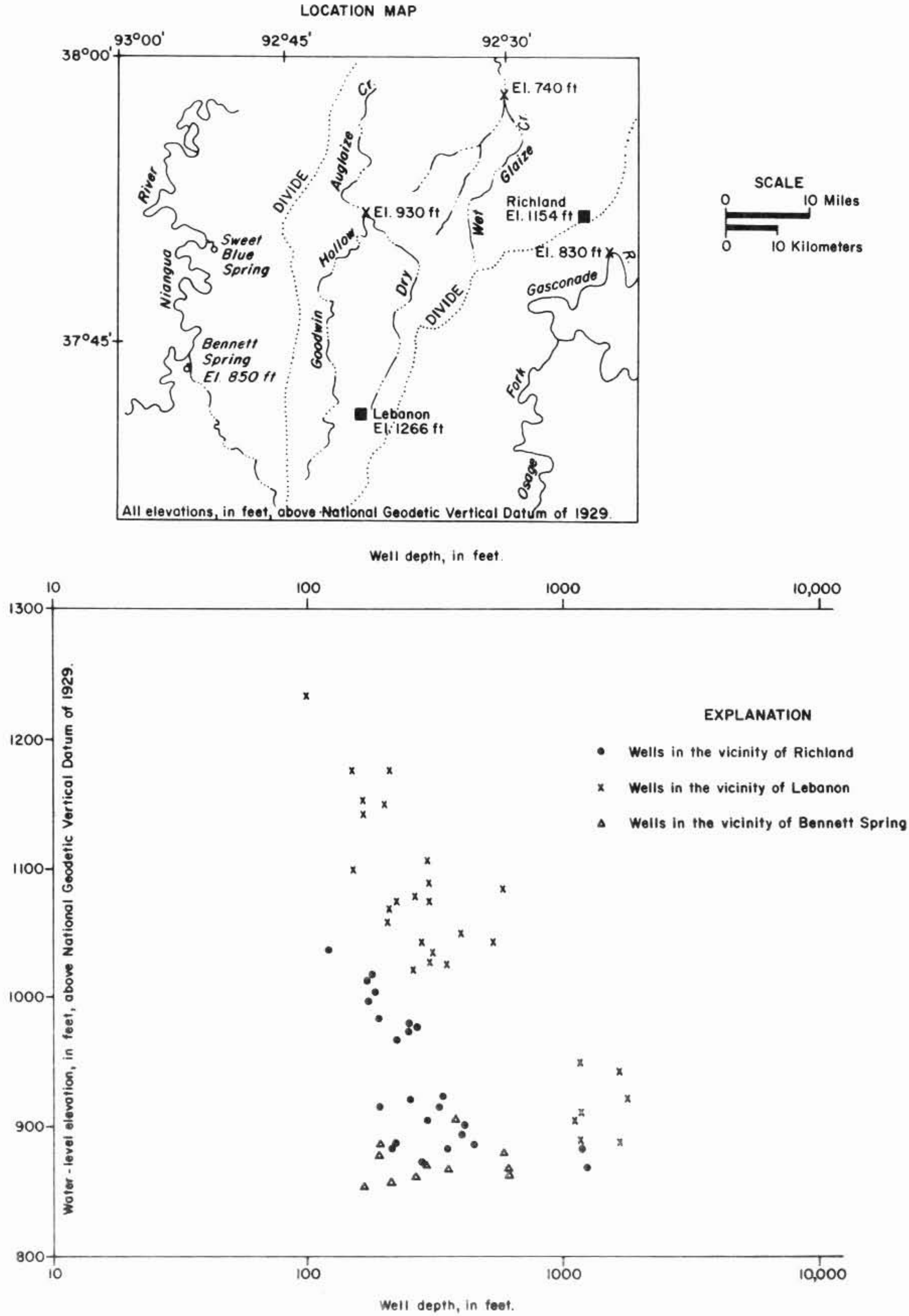


Figure 18. Water-level elevation versus well depth for wells in selected areas.

Niangua River. This increase and the capacity of the rocks underlying Goodwin Hollow to accept large volumes of surface flow during heavy rains, compared to the lesser capacity of Dry Auglaize Creek (see subsequent section on groundwater-surface-water relationships), indicate increasing east-to-west vertical permeability.

The connection between Potosi wells at Lebanon and the Niangua River, as suggested by figure 18, is not readily apparent from the potentiometric map (fig. 13, in pocket). This suggests that there is hydraulic connection through conduits and fractures transmitting water, a condition that cannot be adequately portrayed by water-level contours in such a heterogenous system.

RELATION OF WELL YIELDS TO TOPOGRAPHY AND SUBSURFACE SOLUTION DEVELOPMENT

The large difference in the standard deviation of the ratio of well depth to yield (D/Q) in various basins and topographic situations (table 4) correlates with results of other lines of investigation, which show a relationship between well-completion data, the permeability characteristics of the formations, and topographic situations. An example will illustrate the matter. The mean discharge of wells in North Cobb Creek basin is 17 gpm; in Dry Auglaize Creek basin, 18 gpm. Similarly, the mean D/Q values for the two basins are comparable at 19.6 and 22.8 ft/gal, respectively, but the standard deviations of D/Q are 14.2 and 28.5 ft/gal, respectively. The area with the greater standard deviation is the basin in which solution has affected the bedrock more severely and developed a more heterogenous condition. The relationship correlates with the evidence of anomalous streamflow characteristics in the Dry Auglaize Creek basin and the more normal characteristics of North Cobb Creek basin.

Wells completed in the Gasconade Dolomite along the Marshfield-Lebanon divide and in the Dry Auglaize basin, a recharge area, have similar mean D/Q values, yields, and standard deviations. Along the Osage Fork, on the other hand,

TABLE 4

Well statistics

Area (fig. 4)	Formation	No. of Wells	Mean discharge, (gpm)	Mean D/Q[1] (ft/gal)	Standard deviation, (ft/gal)
North Cobb Creek	Gasconade Dolomite	19	17	19.6	14.2
Dry Auglaize Creek	"	41	18	22.8	28.5
Divide Marshfield-Lebanon	"	33	18	25.8	26.5
Osage Fork	"	16	22	15	16
Divide Marshfield-Lebanon	Roubidoux Formation	15	13	20	11.5
Osage Fork	"	14	21	10.1	9.4
Bennett Spring	Gasconade Dolomite	10	21	13.6	12
Areawide	Potosi Dolomite	22	250	6.5	6.5
South Outcrop	Jefferson City Dolomite	24	9	26	28.5

[1] Ratio of well depth to yield

the values are quite different from those along the divide. Mean yields along Osage Fork are a little higher and mean D/Q values and standard deviations are much lower than those along the divide (table 4). In other words, it is not usually necessary to drill as deeply along Osage Fork to obtain the same quantity of water from the Gasconade Dolomite, and wells are more uniform. The higher average yields are probably due to more saturated material, and higher permeability resulting from solution of the dolomite. The same relation holds true for the Roubidoux Formation, except that standard deviations for both topographic situations are lower than they are for the Gasconade Dolomite.

Wells completed in the Gasconade Dolomite in the vicinity of Bennett Spring, a discharge area, have values similar to those for other discharge areas. The Potosi Dolomite, the highest yielding unit in the section, has the best (lowest) D/Q value, the best mean yield of all units investigated, and the lowest standard deviation. The Jefferson City Formation, a silty dolomite, has the poorest mean yield, the highest D/Q value, and one of the greatest standard deviations for the areas sampled.

GROUNDWATER QUALITY

Analyses of water from selected wells in the study area (table 5 and fig. 19) show that mineralization of groundwater is typical of karstic, high-circulation groundwater regimes. Because of rapid recharge and relatively short residence and transit time to discharge points, the water is not highly mineralized. Continual dilution is equivalent to rapid recharge.

Differences in mineralization between aquifers are subtle and must be evaluated with respect to well depth, the producing aquifers, location of wells with respect to recharge and discharge areas, and the time of the year.

Water entering the system in upland areas, by seepage through residual material, tends to become saturated with calcium and magnesium carbonates rather quickly. In time, however, as more and more carbonate is leached from the residuum, less remains, and unsaturated water is able to penetrate more deeply. Thick residual mantles, such as those west and south of Lebanon, result from long periods of leaching of fractured dolomitic rocks. Data from well logs show 40 to 80 ft of residual material at many sites in this area, which the potentiometric map (fig. 13, in pocket) shows is an important upland recharge area.

During periods of normal or above normal rainfall, thick residuum undoubtedly acts as a storage zone for much water unsaturated with calcium and magnesium carbonates. Slow drainage from residuum into bedrock dissolves soluble carbonates at the rock-residuum contact, leaving an insoluble residue to perpetuate and thicken the residual mantle (T.J. Dean, Missouri Department of Natural Resources, Division of Geology and Land Survey, oral communication, 1977).

Mineralization of groundwater correlates with movement of water from recharge area to discharge area. Figure 20 is a map showing the total mineralization of the water from 38 area wells completed at many depths in all water-bearing units of Cambrian and Ordovician rocks.

TABLE 5

Analyses of water from selected wells in the Osage Fork, Grandglaize, and Niangua River basins (Ojc = Jefferson City-Cotter Dolomite; Or = Roubidoux Formation; Og = Gasconade Dolomite; Cp = Potosi Dolomite)

									Milligrams per liter													
Well no. (fig. 19)	Owner or user	Location	Depth (ft)	Principal water-bearing unit (table 1)	Date of collection	Temperature (°C)	Specific conductance (μmho/cm at 25°C)	pH	Carbonate hardness	Noncarbonate hardness	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (residue at 180°C)	Total nitrate as N	Total nitrite as N
1	Camp Arrowhead	30-17-8dad	500	Or	7-7-77	20	290	8.0	—	—	29	14	1.0	0.9	141	0.0	7.6	1.7	0.1	—	0.02	0.01
2	City of Marshfield, Well 3	30-18-10	940	Og	3-9-77	—	—	[a]8.3	182	100	45	41	9.6	.9	221	0	39	55	.2	215	.70	—
3	R-6 School	31-15-17aaa	650	Og	7-7-77	21	420	7.5	—	—	41	23	1.8	9.7	233	0	1.3	11	.0	—	1.2	.01
4	City of Niangua, Well 1	31-17-20bca	1,050	Og	5-11-76	—	—	[a]8.3	203	17	46	26	3.0	.9	247	0	6.0	4.8	.1	131	.05	—
5	City of Conway, Well 1	32-17-8dcc	954	Cp	8-12-75	—	—	[a]7.9	282	10	58	36	3.9	.9	344	0	5.0	6.4	.1	308	2.5	—
6	Highway Department Rest Stop	32-18-24dba	700	Og	10-6-77	14	390	7.6	163	37	41	24	1.9	1.0	232	0	1.2	1.6	.1	—	.09	.00
7	Cleo Nunn	32-18-36aa	315	Og	9-29-76	16	—	7.0	278	80	79	39	7.6	.8	338	0	71	12	—	—	—	—
8	Dale Griffin	33-14-20cba	300	Og	7-7-77	17	675	7.3	—	—	34	39	.38	1.5	280	0	35	3.7	.1	—	.11	.01
9	Robert Plaster	33-15-28dcd	346	Og	7-7-77	14	570	7.4	—	—	53	36	1.5	.6	330	0	13	1.6	.1	—	.43	.01
10	Laclede County PWSD 3, Well 2	33-16-9aaa	1,215	Cp	4-1-71	—	—	[a]8.2	174	14	43	20	2.3	1.5	211	0	8.6	4.7	—	183	2.2	—
11	Gene Hefton	33-16-30dba	300	Og	6-29-77	23	500	7.4	—	—	50	29	3.6	1.3	230	0	22	1.7	.1	—	.43	.01
12	Laclede County PWSD 3, Well 3	33-17-22	700	Og	2-6-73	—	—	7.8	—	—	44	21	2.5	1.0	244	0	5.8	2.2	.2	229	.40	—
13	Gasconade C-4 School	34-14-26dda	230	Or	10-6-77	15	550	7.2	226	64	55	36	2.7	1.1	270	0	7.7	6.5	.1	—	.26	.00
14	Cliff Wallace	34-15-10ccc	320	Og	7-7-77	16	485	7.5	—	—	51	28	2.3	1.0	293	0	5.5	1.8	.0	—	.53	.00
15	Laclede County PWSD 3, Well 1	34-15-17	1,280	Og	6-9-76	—	—	[a]8.1	187	0	42	20	.9	.7	238	0	.0	1.3	.1	111	.70	—
16	Harold Mahan	34-15-30cac	270	Og	7-7-77	16	480	7.2	—	—	48	27	2.7	.8	279	0	5.9	2.4	.0	—	.45	.00
17	Laclede County PWSD 1, Well 2	34-16-2ba	1,150	Cp	8-19-75	—	—	[a]8.1	228	10	46	30	3.0	.9	278	0	7.9	2.9	.1	264	.20	—
18	Laclede County PWSD 1, Well 1	34-16-6add	1,100	Cp	7-7-71	—	—	[a]7.8	184	0	38	22	1.6	.4	233	0	2.7	1.9	.1	234	1.2	—
19	Lebanon Country Club	34-16-6dca	509	Og	6-29-77	21	340	7.0	175	45	42	24	2.7	.9	190	0	10	3.0	.0	—	.07	.01
20	City of Lebanon, Well 3	34-16-11cad	1,625	Cp	9-10-58	—	—	7.5	176	10	48	16	3.5	—	215	0	6.2	6.9	.1	172	.17	—
21	Henry Myers	34-17-6ada	360	Og	6-29-77	19	540	7.4	—	—	55	33	2.9	.9	310	0	7.5	3.7	.1	—	.71	.01
22	Long Lane Elementary School	34-18-33dcd	323	Og	10-6-77	15	560	7.4	249	41	61	35	4.2	12.0	340	0	3.0	10	.1	—	.67	.00
23	Mickey McGuire	34-20-15abb	240	Ojc	10-6-77	13	650	7.2	276	74	73	42	2.9	1.5	340	0	7.9	4.3	.1	—	.19	.00
24	City of Buffalo, Well 3	34-20-26aba	1,050	Cp	5-21-75	—	—	[a]8.2	229	0	48	26	1.8	.6	284	0	9.0	3.2	.1	238	.00	—
25	Breeden	35-14-5aac	200	Og	8-23-77	18	860	7.1	—	—	85	49	2.6	3.0	380	0	22	36	.1	—	17	.01
26	Cliff Springs Camp	35-14-9bab	450	Og	7-5-77	20	520	7.3	—	—	49	28	5.1	1.1	263	0	15	15	.1	—	.22	.01
27	Brady	35-15-24aac	140	Og	8-23-77	15	590	7.3	—	—	64	38	3.0	.4	350	0	9.9	9.2	.1	—	.68	.02
28	David Taylor	35-16-1dd	300	Og	7-5-77	16	560	7.0	—	—	56	33	3.2	.6	336	0	5.8	2.4	.0	—	.27	.00
29	Bennett Spring State Park, Well 1	35-17-31bcc	600	Cp	7-11-75	—	—	[a]8.1	296	31	60	43	1.4	.7	360	0	11	3.9	.1	328	.00	—
30	Laclede County PWSD 2, Well 1	36-14-31bad	1,235	Cp	11-21-75	—	—	[a]8.3	266	0	60	28	3.5	1.0	324	0	11	5.1	.1	324	.90	—
31	J.J. Schmalstig	36-17-3abc	340	Og	6-29-77	16	650	6.9	—	—	75	46	3.0	.7	340	0	5.5	2.7	.1	—	.18	.01
32	Elbert Hann	36-17-24da	330	Og	7-5-77	20	375	7.9	—	—	35	20	1.9	.9	194	0	4.7	6.6	.0	—	2.0	.00
33	Walter Deberry	37-14-23caa	300	Og	7-5-77	20	480	7.5	—	—	48	28	4.0	.7	210	0	7.2	3.6	.0	—	1.8	.00
34	Doyle Pierce	37-15-20aad	282	Og	7-5-77	17	650	7.1	—	—	65	37	4.0	1.0	360	0	6.9	14	.0	—	2.6	.01
35	Ozark Fisheries	37-15-25cca	935	Cp	7-5-77	18	278	7.3	—	—	26	14	1.5	1.2	144	0	4.6	1.9	.0	—	.74	.01
36	Camden PWSD 2, Well 2	37-16-4dd	848	Og	7-5-77	20	500	7.4	—	—	52	28	4.3	2.6	240	0	34	14	.0	—	2.2	.00
37	Ken Wallendar	37-16-30bb	400	Og	8-31-76	17	—	7.4	285	32	71	34	5.8	.3	347	0	3.2	7.8	—	—	—	—
38	Gail Heritage	38-16-22aa	400	Og	12-15-76	15	—	7.9	288	0	88	16	4.7	1.5	351	0	4.9	9.3	—	—	—	—

[a]Laboratory pH, all others are field determined.

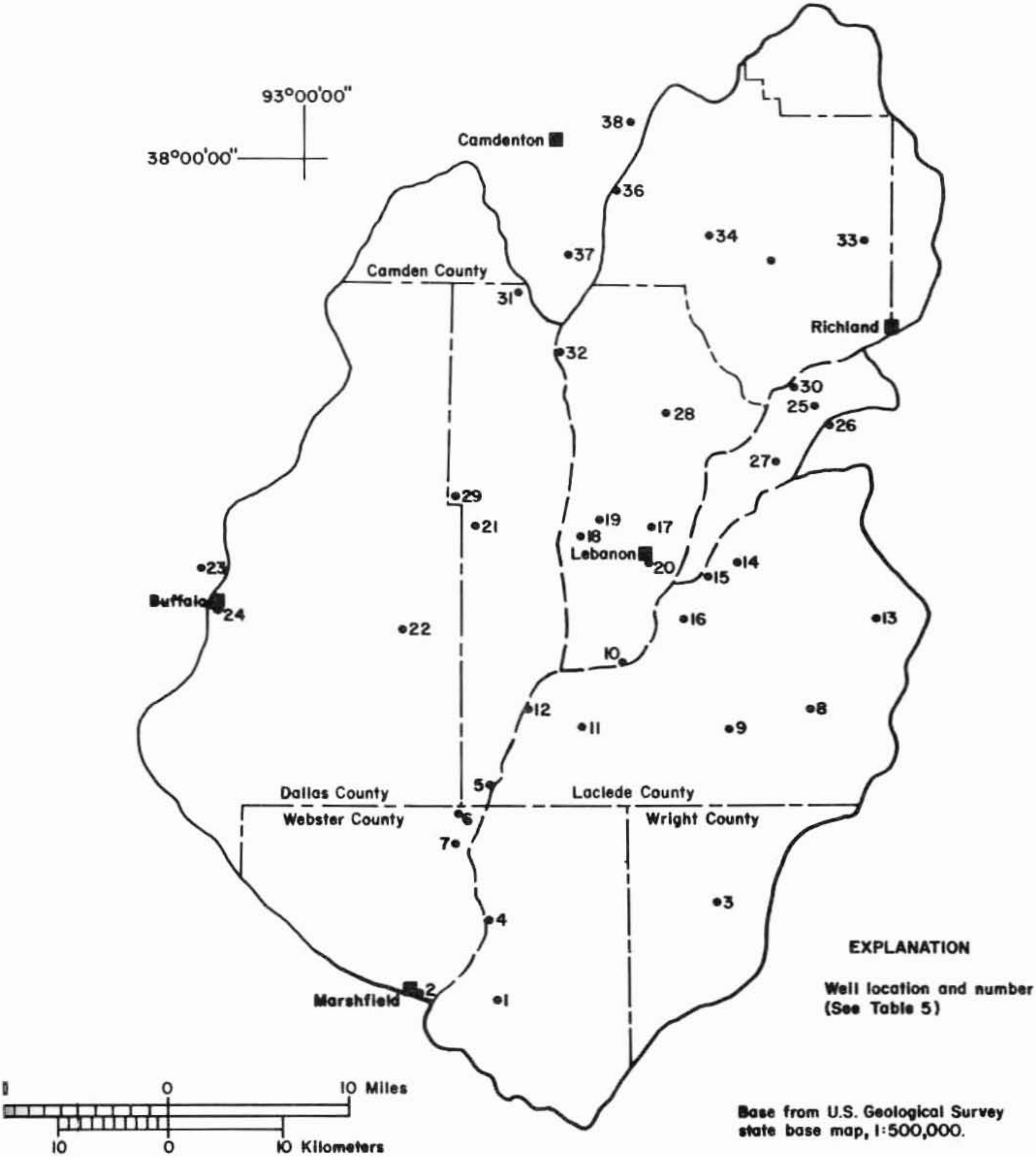


Figure 19. Location of wells where water-quality data were obtained.

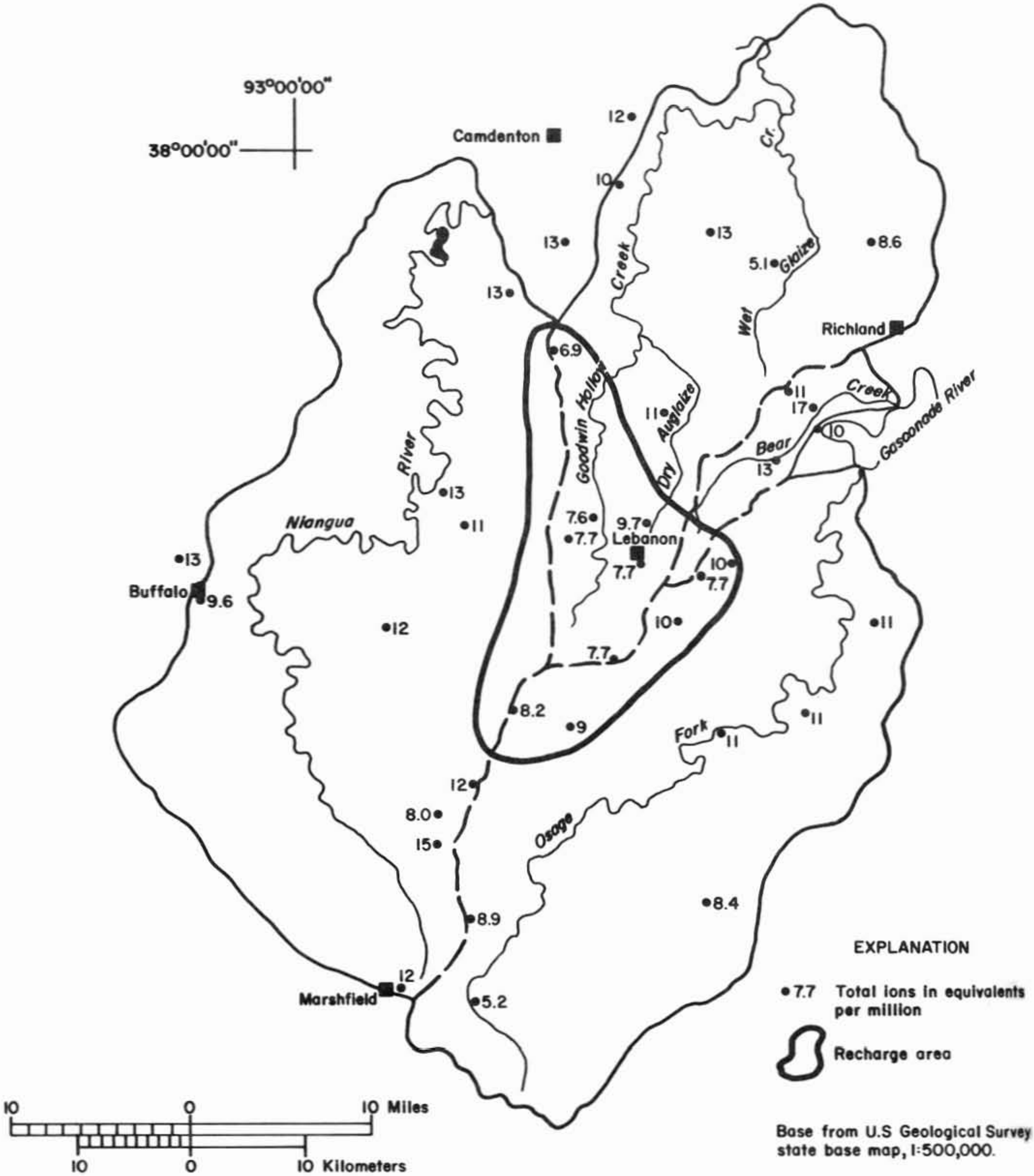


Figure 20. Ion concentrations in groundwater.

In the area along the divides in the center of the project area, the concentrations of total ions in milliequivalents per liter (meq/l) are generally lower and more uniform than in surrounding areas. The potentiometric map shows that this is a recharge area. Wells within it are 270 to 1625 ft deep and obtain most of their water from the Gasconade Dolomite, Gunter Sandstone, and Potosi Dolomite. The relative uniformity of the mineralization indicates vertical as well as horizontal mixing of the water through the section. The 11 ion-concentration values range from 6.9 to 10 meq/l, the medium value is 7.7 meq/l. Twenty-five ion-concentration values outside the central area range from 5.2 to 17 meq/l; the median value is 11 meq/l. The range in ion concentrations in the circumferential area represents a variety of hydrologic conditions, including recharge and discharge. For example, the low concentrations in the upper part of the Osage Fork basin probably represent recharge conditions, whereas the high concentration at Bennett Spring, in west-central Laclede County (13 meq/l), and three concentrations of 11 meq/l along Osage Fork, in southeastern Laclede County, probably represent discharge conditions.

A divide area with a considerable range in concentration values suggests slower recharge and less mixing. Along the divide extending from Marshfield to the southwestern corner of Laclede County, the sampled wells range from 315 to 1050 ft deep and the values of mineralization range from 8.0 to 15 meq/l, with a median value of 12 meq/l.

Admittedly, the foregoing analysis of the data is very general because of the small number of analyses in relation to the size of the area and the diversity of the recharge and discharge characteristics. Within a basin such as Osage Fork are many subbasins with widely varying recharge and discharge characteristics. For a more comprehensive analysis of the relation of mineralization to recharge and discharge, additional analyses are needed; sampling locations should be determined by the flow system as determined from streamflow, water-level, and geologic investigations.

In this respect, carbonate-saturation data have been used successfully in other carbonate terranes in the United States to show the movement of water from recharge to discharge areas and to correlate such movement with yields of wells and springs (Norris, 1971; Feder, 1970; Back, 1963). It seems certain such studies would strongly support the findings of this project. For future basin studies, some carbonate-saturation data should be collected and evaluated.

Two wells on Bear Creek (25 and 27 in table 5) were sampled to determine if there are any differences, in kind and concentration of dissolved constituents, that might be associated with the flow system in the valley. Results of the analyses are given in table 5, except for fecal coliform and streptococcus values, which were less than 1 colony per 100 milliliters (col/100 ml) for both wells.

Well 27 is adjacent to a gaining reach of Bear Creek (fig. 21); well 25 is at a dairy farm, downstream in a losing reach of the stream. The water level in Well 27 stands above the stream channel; the level in Well 25, about 40 ft below the stream channel. Both wells are open in the Roubidoux Formation and Gasconade Dolomite and have similar lengths of casing. A sinkhole formerly used as a garbage dump lies midway between the two wells (fig. 21). It is not known whether the dairy operation, the sinkhole, or a combination of the two is the source of the high nitrate, chloride, sulfate, and potassium concentrations in Well 25, but such concentrations do

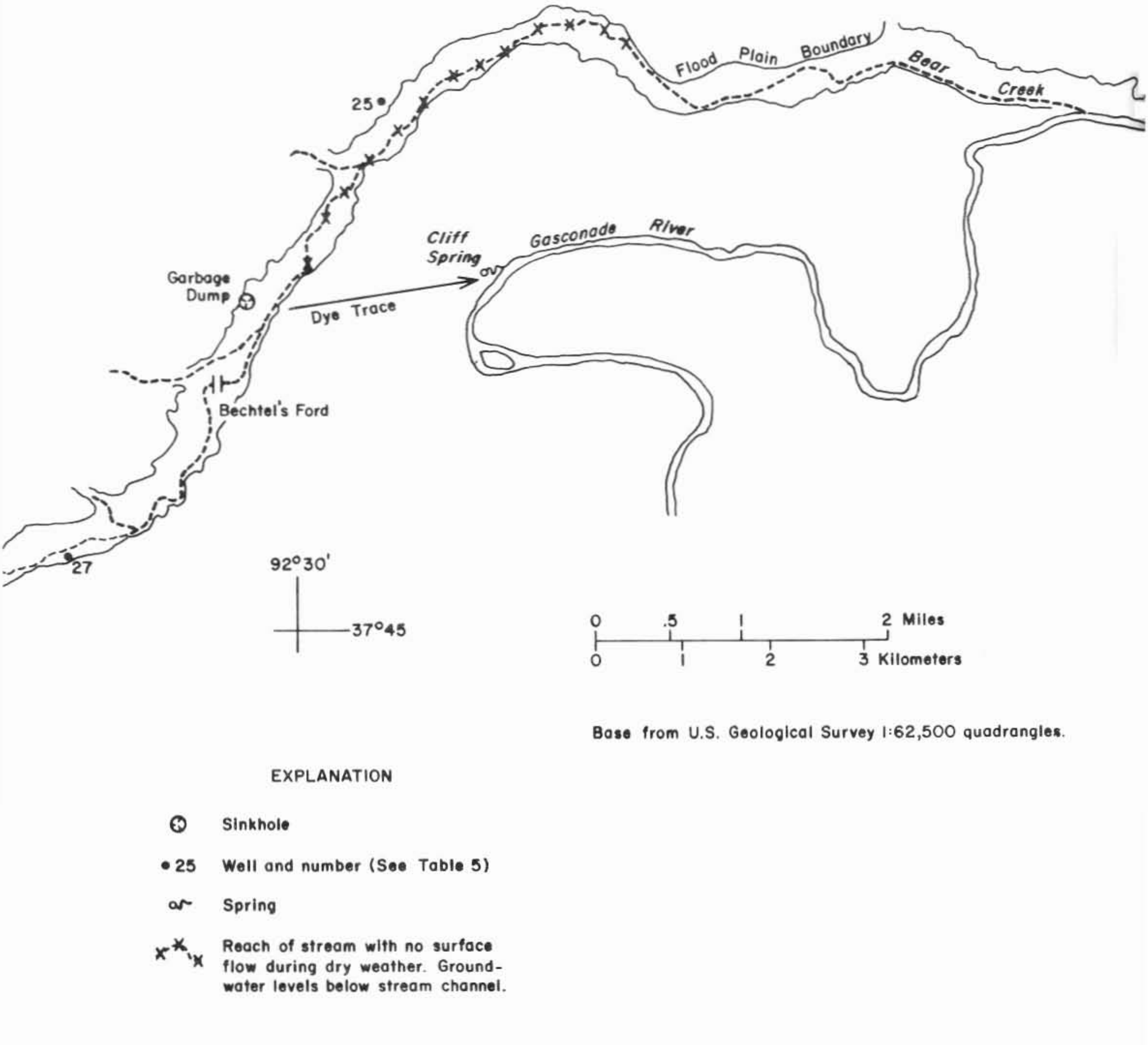


Figure 21. Locations of wells in Bear Creek basin where water-quality data are indicative of ground-water-surface-water relationships.

indicate a source of pollution within the losing stream reach.

The foregoing suggests that any source of pollution in a recharge area where materials at the surface can be carried downward to bedrock is a potential hazard to water wells in that same area. Since many streams in the study area lose their flow to bedrock, the potential for pollution is great.

SURFACE WATER

The basis of the surface-water information in this report is a data-collection network of 134 stream gaging sites (figs. 22, 23, and 24), two of which, Osage Fork at Drynob, and Bennett Spring at Bennett Spring in the Niangua River basin, are continuous-record stations, used in this study as index stations for estimating low-flow frequency characteristics. The others are partial-record stations and miscellaneous sites where periodic observations of streamflow, temperature, and specific conductance were made.

The purpose of surface-water data collection was to provide basic information on flow characteristics (primarily low flows) for all streams in the area. These data were then used to study the relationship between spatial and temporal patterns of surface-water and groundwater flow.

MAGNITUDE AND FREQUENCY OF LOW FLOWS

The low-flow frequency data for streamflow stations and springs, as shown in table 6, were computed by procedures described by Skelton (1976) and provide reliable estimates of median values (the 2-year recurrence interval), with somewhat less reliable estimates for more extreme events. There is no way, however, to evaluate mathematically the magnitude of the errors involved in these procedures.

The frequency data shown in table 6 are the 7-day Q_2, 7-day Q_{10}, and 7-day Q_{20}, the values most frequently requested. The 7-day Q_{10} is of special interest, because it has been designated by the Missouri Clean Water Commission as the maximum flow for design of waste-treatment facilities. For the two continuous-record stations in the area (figs. 22 and 23, map nos. 23 and 31), values for 1, 3, 14, 30, 60, 90, 120, and 183 consecutive days can be obtained from the Missouri district office of the U.S. Geological Survey, Rolla, Missouri.

In some cases there are differences in the low-flow frequency values of streams of comparable size in adjacent basins, and the values sometimes decrease downstream. This is primarily because of differences in infiltration rates in losing or non-gaining reaches of the streams. In this report, discussions of structural trends and effects on flow patterns are contained in the sections *Structure* and *Groundwater-Surface-Water Relationships;* variations in flow are discussed under *Seepage Runs.*

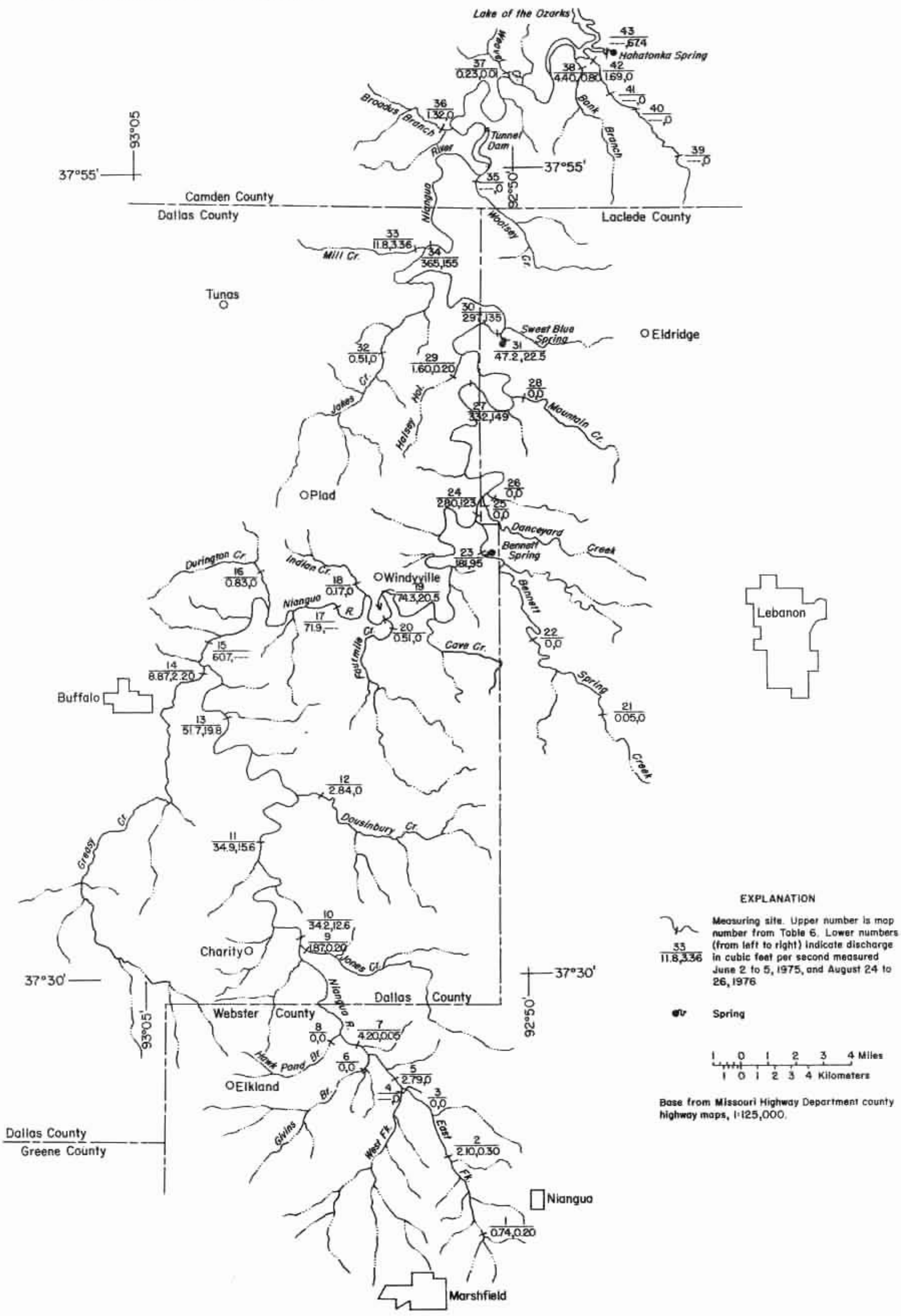


Figure 22. Data-collection network and seepage-run measurements in the Niangua River basin.

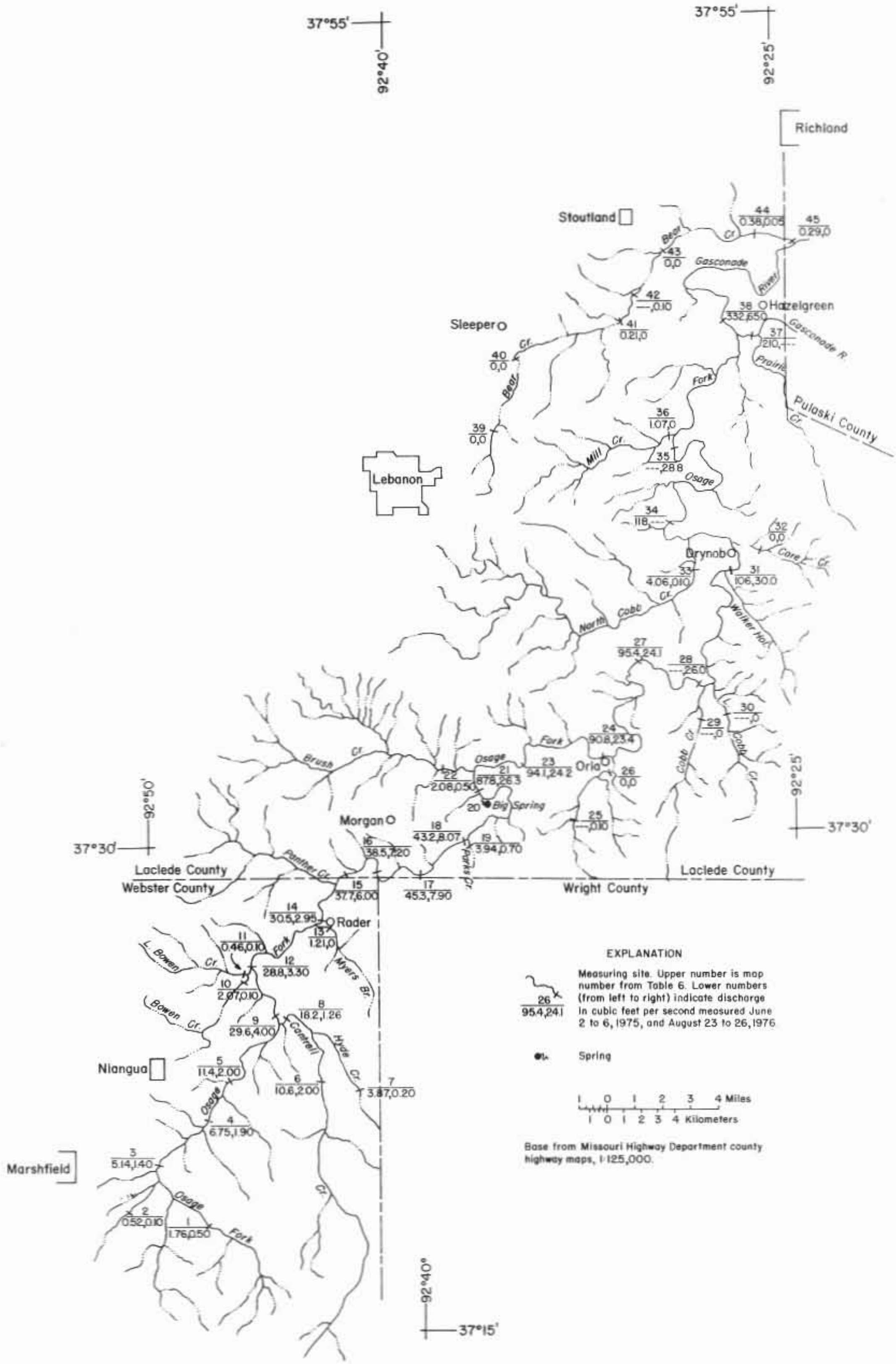


Figure 23. Data-collection network and seepage-run measurements in Osage Fork and Bear Creek basins.

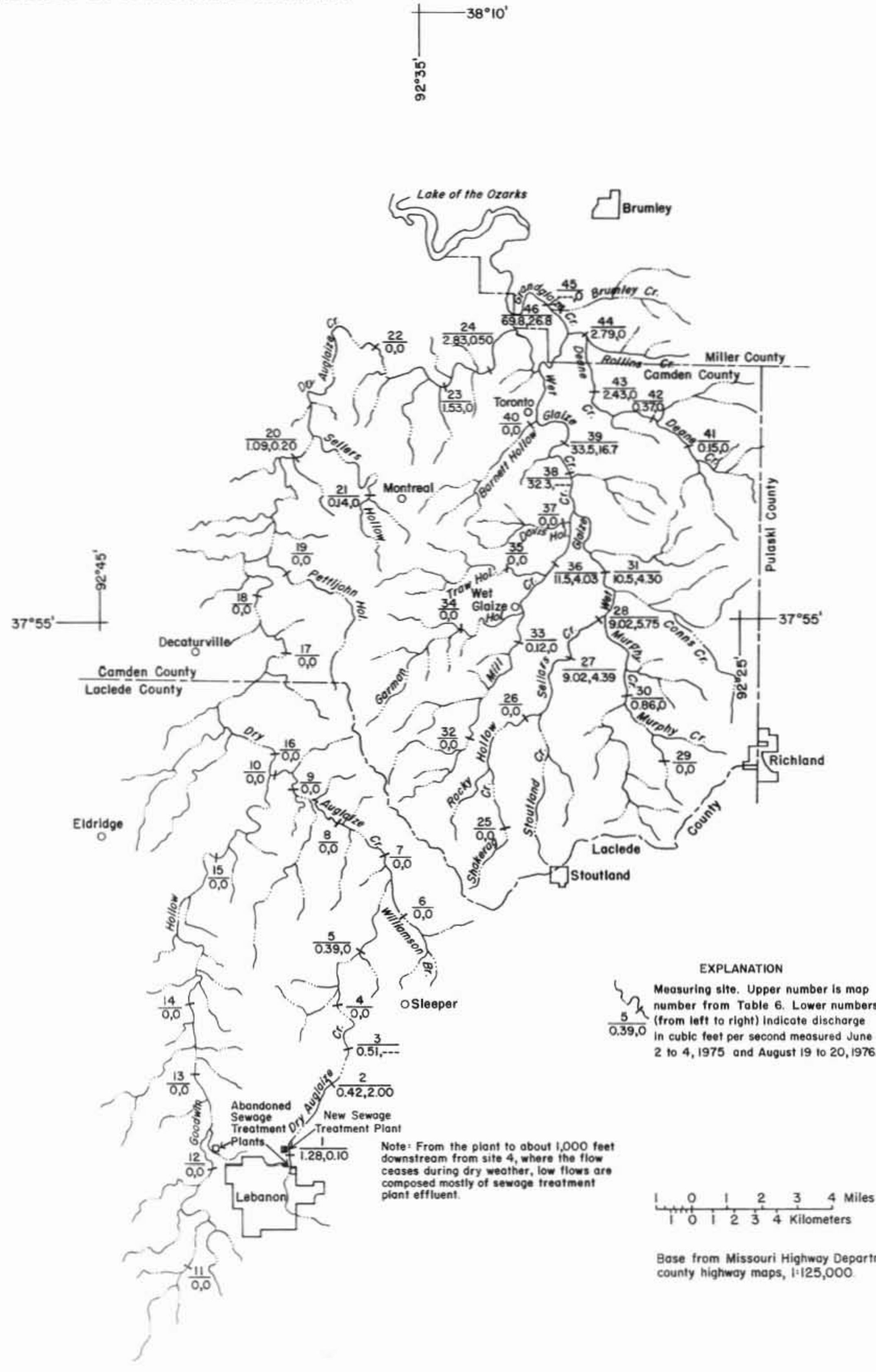


Figure 24. Data-collection network and seepage-run measurements in Grandglaize Creek basin.

TABLE 6

Hydrologic data at low-flow sites

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft³/s)	Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft³/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 22)			NIANGUA RIVER BASIN								
1	East Fork Niangua River	SE¼ SW¼ sec. 25, T. 31 N., R. 18 W., at bridge on County Highway CC, 2 mi northeast of Marshfield, Webster County.	6.7	6-4-75	0.74	440	18.5	—	0.1	0	0
				8-25-75	0	450	27.0	—			
				11-1-75	1.00	390	11.5	—			
				8-24-76	.20	400	23.0	—			
2	East Fork Niangua River	NW¼ NW¼ sec. 14, T. 31 N., R. 18 W., at bridge on Interstate Highway 44, 4 mi north of Marshfield, Webster County.	17.8	6-4-75	2.10	430	19.0	—	.4	.1	0
				8-25-75	.54	440	25.0	—			
				11-11-75	3.20	380	13.5	—			
				8-24-76	.30	—	—	—			
3	East Fork Niangua River	NE¼ SW¼ sec. 33, T. 32 N., R. 18 W., at ford on county highway, 6 mi east of Elkland, Webster County.	26.6	6-4-75	0	400	21.0	—	0	0	0
				7-17-75	0	—	—	—			
				8-25-75	0	—	—	—			
				11-11-75	0	—	—	—			
				2-25-76	2.00	360	12.0	—			
				8-24-76	0	—	—	—			
4	West Fork Niangua River	NE¼ SW¼ sec. 33, T. 32 N., R. 18 W., 100 ft upstream from confluence with East Fork Niangua River, 6 mi east of Elkland, Webster County.	27.8	7-17-75	0	—	—	—	0	0	0
				11-11-75	3.80	375	15.0	—			
				2-25-76	5.50	360	12.0	—			
				8-24-76	0	—	—	—			
5	Niangua River	SW¼ NW¼ sec. 33, T. 32 N., R. 18 W., at low-water bridge on County Highway Y, 5 mi southwest of Conway, Webster County.	57.8	5-20-75	5.23	380	23.0	24.5	0	0	0
				6-4-75	2.79	400	22.5	—			
				7-17-75	.06	400	29.0	—			
				8-25-75	0	400	29.0	—			
				9-10-75	.42	382	21.5	—			
				11-11-75	3.50	380	14.0	—			
				2-25-76	9.50	380	12.0	—			
				8-25-76	0	—	—	—			
				10-18-76	0	—	—	—			
				8-25-77	.20	390	24.5	—			
6	Givins Branch	NW¼ NW¼ sec. 32, T. 32 N., R. 18 W., at ford on county highway, 5 mi northeast of Elkland, Webster County.	16.8	6-4-75	0	400	25.0	—	0	0	0
				8-25-75	0	—	—	—			
				11-11-75	0	—	—	—			
				2-25-76	.30	370	11.5	—			
				8-25-76	0	—	—	—			
7	Niangua River	NE¼ NE¼ sec. 30, T. 32 N., R. 18 W., at bridge on county highway, 5 mi northeast of Elkland, Webster County.	85.2	6-4-75	4.20	390	22.0	—	.05	0	0
				8-25-75	.08	400	26.0	—			
				11-12-75	3.80	365	10.5	—			
				8-25-76	.05	—	—	—			
8	Hawk Pond Branch	NE¼ NE¼ sec. 25, T. 32 N., R. 19 W., at ford on county highway, 4 mi northeast of Elkland, Webster County.	6.8	6-4-75	0	450	25.0	—	0	0	0
				8-25-75	0	—	—	—			
				11-12-75	0	—	—	—			
				2-25-76	.05	340	13.0	—			
				8-25-76	0	—	—	—			

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft³/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft³/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 22, continued)		NIANGUA RIVER BASIN (continued)									
9	Jones Creek	NE¼ NE¼ sec. 11, T. 32 N., R.19 W., at bridge on county highway, 2 mi east of Charity, Dallas County.	33.9	6-4-75	1.87	340	21.5	—	0.1	0	0
				8-25-75	.03	380	29.0	—			
				11-12-75	1.80	320	9.0	—			
				2-25-76	2.00	310	12.5	—			
				8-25-76	.20	—	—	—			
10	Niangua River	NE¼ SE¼ sec. 2, T. 32 N., R. 19 W., at bridge on County Highway M, 1½ mi east of Charity, Dallas County.	140	6-4-75	34.2	390	19.0	—	13	8	6.5
				8-25-75	11.5	400	22.5	—			
				11-12-75	36.0	355	10.5	—			
				2-25-76	46.0	350	14.0	—			
				8-25-76	12.6	380	19.0	—			
				5-24-77	14.7	—	21.0	—			
11	Niangua River	NE¼ NW¼ sec. 22, T. 33 N., R. 19 W., at ford on county highway, 6 mi southeast of Buffalo, Dallas County.	159	6-4-75	34.9	360	21.5	—	16	11	9.8
				8-25-75	15.8	400	26.5	—			
				8-25-76	15.6	360	22.5	—			
12	Dousinbury Creek	SW¼ NE¼ sec. 12, T. 33 N., R. 19 W., at bridge on County Highway JJ, 7 mi southwest of Buffalo, Dallas County.	37.4	5-20-75	5.29	300	24.0	24.5	0	0	0
				6-4-75	2.84	310	24.0	—			
				7-16-75	.94	325	29.5	—			
				8-25-75	0	360	28.0	—			
				11-13-75	1.50	310	10.0	—			
				8-25-76	0	—	—	—			
				10-18-76	0	—	—	—			
13	Niangua River	SW¼ SW¼ sec. 28, T. 34 N., R. 19 W., at bridge on State Highway 32, 2½ mi east of Buffalo, Dallas County.	210	6-4-52	56.9	—	24.0	—	21	14	12
				7-13-54	14.7	—	—	—			
				5-21-62	62.8	—	25.0	—			
				9-3-63	19.5	—	23.0	—			
				10-2-63	16.5	—	16.0	—			
				11-5-63	16.3	—	12.0	—			
				10-21-64	15.2	405	11.0	19.0			
				8-22-67	31.5	350	23.0	—			
				9-8-67	25.0	380	19.0	—			
				8-31-70	20.9	390	24.5	24.0			
				9-28-71	28.4	380	23.0	25.0			
				6-4-75	51.7	370	23.0	—			
				7-16-75	29.8	400	24.0	—			
				8-25-75	19.3	400	27.0	—			
				8-25-76	19.8	350	21.5	—			
				9-9-76	17.6	400	18.0	—			
				10-18-76	20.2	400	10.5	13.5			
				8-25-77	27.9	390	23.0	26.5			
14	Greasy Creek	NW¼ NW¼ sec. 20, T. 34 N., R. 19 W., at ford on county highway, 1½ mi northeast of Buffalo, Dallas County.	66.8	6-5-75	8.87	460	22.5	—	1.0	0.4	—
				7-16-75	1.52	400	30.0	—			
				8-25-76	2.20	360	22.0	—			
				10-18-76	.59	400	11.0	14.0			

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft³/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft³/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 22, continued)			NIANGUA RIVER BASIN (continued)								
15	Niangua River	NE¼ NW¼ sec. 17, T. 34 N., R. 19 W., at bridge on county highway, 3 mi northeast of Buffalo, Dallas County.	294	10-2-74	20.0	—	—	—	—	—	—
				6-5-75	60.7	390	23.0	—			
16	Durington Creek	SW¼ NW¼ sec. 3, T. 34 N., R. 19 W., at ford on county highway, 3½ mi southwest of Plad, Dallas County.	7.6	6-5-75	.83	400	23.0	—	—	—	—
				8-25-75	0	—	—	—			
				11-30-77	2.50	400	7.0	—			
17	Niangua River	SW¼ SW¼ sec. 6, T. 34 N., R. 18 W., at old bridge crossing, 2 mi southwest of Windyville, Dallas County.	323	6-5-75	71.9	380	24.0	—	—	—	—
18	Indian Creek	NE¼ SE¼ sec. 6, T. 34 N., R. 18 W., at ford on county highway, 1 mi west of Windyville, Dallas County.	8.4	6-5-75	.17	430	23.0	—	0	0	0
				8-25-76	0	—	—				
19	Niangua River	NE¼ NE¼ sec. 8, T. 34 N., R. 18 W., at bridge on County Highway K, 2 mi south of Windyville, Dallas County.	335	7-13-54	14.1	—	—	—	26	17	14
				8-22-67	40.7	350	22.0	—			
				9-28-71	36.6	370	22.5	24.0			
				6-5-75	74.3	360	24.0	—			
				7-16-75	33.1	360	25.0	—			
				8-25-76	20.5	—	—	—			
				10-18-76	22.3	400	10.5	12.0			
20	Fourmile Creek	NW¼ SW¼ sec. 9, T. 34 N., R. 18 W., at ford on County Highway P, 2½ mi south of Windyville, Dallas County.	18.8	6-5-75	.51	400	19.0	—	0	0	0
				11-13-75	0	360	13.5	—			
				2-25-76	0	—	—	—			
				8-25-76	0	—	—	—			
				10-18-76	0	—	—	—			
21	Bennett Spring Creek	NE¼ SE¼ sec. 27, T. 34 N., R. 17 W., at bridge on State Highway 32, 6½ mi southwest of Lebanon, Laclede County.	8.9	6-2-75	.05	340	17.0	—	0	0	0
				8-25-75	0	—	—	—			
				8-25-76	0	—	—	—			
22	Bennett Spring Creek	SE¼ SW¼ sec. 8, T. 34 N., R. 17 W., at ford on county highway, 8 mi west of Lebanon, Laclede County.	23.4	6-2-75	0	—	—	—	0	0	0
				11-13-75	0	—	—	—			
				8-25-76	0	—	—	—			
23	Bennett Spring[1]	NW¼ sec. 1, T. 34 N., R. 18 W., in Bennett Spring State Park, 10 mi northwest of Lebanon, Dallas County. (Continuous-record station).	—	6-2-75	181	370	14.0	—	80	62	57
				8-25-76	95	—	—	—			
24	Niangua River	SE¼ SE¼ sec. 25, T. 35 N., R. 18 W., at bridge on State Highway 64 at Bennett Spring State Park, Dallas County.	438	5-22-67	546	—	—	—	135	100	88
				7-26-67	197	—	—	—			
				11-20-67	295	320	12.0	—			
				4-16-68	487	300	—	—			
				10-30-68	163	—	—	—			
				3-31-69	642	310	9.0	—			
				5-21-69	322	340	20.0	—			
				8-4-69	183	360	21.0	—			
				9-24-69	158	380	19.0	—			
				3-3-70	686	370	11.0	—			
				5-26-70	308	310	16.0	—			
				9-1-70	126	—	15.5	23.0			

[1]Measurements that are shown were made during seepage runs. Many others are available in files of the U.S. Geological Survey at Rolla, Mo.

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (μmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 22, continued)			NIANGUA RIVER BASIN (continued)								
24	Niangua River (cont.)	SE¼ SE¼ sec. 25, T. 35 N., R. 18 W., (continued)	438	10-14-70	672	320	15.0	—			
				2-10-71	357	280	6.0	—			
				4-6-71	263	350	11.0	—			
				8-4-71	183	—	18.5	—			
				4-5-72	218	400	12.0	—			
				11-14-72	3,540	170	10.0	4.0			
				6-2-75	280	360	17.5	—			
				8-25-76	123	440	19.0	—			
25	Danceyard Creek	NW¼ SW¼ sec. 30, T. 35 N., R. 17 W., at ford on county highway, half a mile north of Bennett Spring, Laclede County.	9.2	6-2-75	0	—	—	—	0	0	0
				11-14-75	0	—	—	—			
				8-26-76	0	—	—	—			
26	Little Danceyard Creek	NE¼ NW¼ sec. 30, T. 35 N., R. 17 W., at ford on county highway, 1 mi north of Bennett Spring, Laclede County.	4.4	6-2-75	0	—	—	—	0	0	0
				11-14-75	0	—	—	—			
				8-26-76	0	—	—	—			
27	Niangua River	NW¼ NE¼ sec. 1, T. 35 N., R. 18 W., at old bridge on county highway, 4½ mi northwest of Bennett Spring, Dallas County.	464	6-2-75	332	360	18.0	—	—	—	—
				8-26-76	149	360	18.0	—			
28	Mountain Creek	SW¼ SW¼ sec. 4, T. 35 N., R. 17 W., at ford on county highway, 4½ mi southwest of Eldridge, Laclede County.	28.7	6-2-75	0.0	—	—	—	0	0	0
				11-14-75	0	—	—	—			
				8-26-76	0	—	—	—			
29	Halsey Hollow	SE¼ SE¼ sec. 35, T. 36 N., R. 18 W., at ford on county highway, 8 mi southeast of Tunas, Dallas County.	4.0	6-2-75	1.60	—	—	—	0.3	—	—
				11-20-75	2.20	425	9.5	—			
				2-25-76	1.80	400	8.5	—			
				8-26-76	.20	500	20.5	—			
30	Niangua River	SW¼ NE¼ sec. 30, T. 36 N., R. 17 W., at end of county highway, 5 mi west of Eldridge, Laclede County.	506	6-2-75	297	360	21.0	—	—	—	—
				8-26-76	135	—	—	—			
31	Sweet Blue Spring[1]	SE¼ NE¼ sec. 30, T. 36 N., R. 17 W., at fishing resort, 5 mi west of Eldridge, Laclede County.	—	6-2-75	47.2	420	13.5	—	15	10	—
				8-26-76	22.5	—	15.0	—			
				10-21-76	23.6	450	14.0	12.5			
				8-24-77	20.7	430	14.5	—			
32	Jakes Creek	NE¼ NW¼ sec. 33, T. 36 N., R. 18 W., at ford at end of County Highway YY, 5 mi southeast of Tunas, Dallas County.	18.4	5-21-75	3.0	410	21.0	24.0	0	0	0
				6-3-75	.51	440	27.0	—			
				7-16-75	0	—	—	—			
				11-20-75	.90	390	9.2	—			
				2-25-76	1.80	370	9.0	—			
				8-26-76	0	—	—	—			
				10-19-76	0	—	—	—			
33	Mill Creek	SE¼ NE¼ sec. 10, T. 36 N., R. 18 W., at ford on county road, 7 mi northeast of Tunas, Dallas County.	11.4	6-3-75	11.8	420	19.0	—	4.0	2.5	—
				11-20-75	10.0	410	10.0	—			
				8-26-76	3.36	460	20.5	—			
				8-24-77	2.73	470	21.5	—			

[1]Measurements that are shown were made during seepage runs. Many others are available in files of the U.S. Geological Survey at Rolla, Mo.

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 22, continued)			NIANGUA RIVER BASIN (continued)								
34	Niangua River	SW¼ NW¼ sec. 11, T. 36 N., R. 18 W., about 200 ft downstream from Mill Creek inflow, 7 mi northeast of Tunas, Dallas County.	564	9-29-71	192	440	23.0	28.0	175	135	--
				6-3-75	365	360	20.5	--			
				7-16-75	191	365	23.0	--			
				8-26-76	155	--	--	--			
				9-8-76	150	390	22.5	--			
				10-19-76	165	410	10.5	6.0			
				8-24-77	163	380	24.0	--			
35	Woolsey Creek	NE¼ NE¼ sec. 36, T. 37 N., R. 18 W., near mouth, 2 mi south of Tunnel Dam, Camden County.	18.8	8-26-76	0	--	--	--	0	0	0
36	Broadus Branch	SW¼ NE¼ sec. 23, T. 37 N., R. 18 W., at ford on county highway, 5 mi southeast of Macks Creek, Camden County.	10.2	6-3-75	1.32	450	21.0	--	0	0	0
				11-14-75	2.20	440	12.0	--			
				8-26-76	0	--	--	--			
37	Weaver Creek	SE¼ NE¼ sec. 7, T. 37 N., R. 17 W., at crossing near the mouth, 4½ mi southwest of Camdenton, Camden County.	3.2	6-3-75	.23	400	21.0	--	.1	0	0
				8-26-76	.01	430	26.0	--			
38	Bank Branch	SE¼ SW¼ sec. 3, T. 37 N., R. 17 W., at bridge on County Highway K, 2½ mi southwest of Camdenton, Camden County.	4.6	6-3-75	4.40	480	19.0	--	1.1	.6	--
				11-14-75	3.00	435	11.0	--			
				8-26-76	.80	500	26.0	--			
39	Spencer Creek	NE¼ SE¼ sec. 30, T. 37 N., R. 16 W., at ford on county highway, 1½ mi northwest of Decaturville, Camden County.	--	10-15-71	0.2	--	13.5	--	0	0	0
				8-26-76	0	--	--	--			
40	Spencer Creek	SW¼ NE¼ sec. 13, T. 37 N., R. 17 W., about 2000 ft upstream from Turkeypen Hollow, Camden County.	--	10-15-71	0	--	--	--	0	0	0
				8-26-76	0	--	--	--			
41	Spencer Creek	NW¼ NE¼ sec. 14, T. 37 N., R. 17 W., at ford on county highway, 1½ mi south of County Highway D, Camden County.	--	10-15-71	.60	--	--	--	0	0	0
				11-14-75	1.90	400	10.5	--			
				8-26-76	0	500	19.5	--			
42	Spencer Creek	SE¼ SE¼ sec. 3, T. 37 N., R. 17 W., at bridge on County Highway D, 2 mi southwest of Camdenton, Camden County.	12.8	6-3-75	1.69	450	21.0	--	.1	0	0
				11-14-75	2.00	440	11.0	--			
				8-26-76	0	--	--	--			
43	Hahatonka Spring[1]	Center sec. 2, T. 37 N., R. 17 W., at Hahatonka, 2 mi south of Camdenton, Camden County.	--	8-26-76	67.4	400	14.0	--	48	40	--
				10-21-76	65.5	430	14.0	11.5			
				3-8-77	58.9	--	14.0	--			
				5-25-77	56.5	--	14.0	--			
				8-23-77	57.3	390	14.0	--			
(fig. 24)			GRANDGLAIZE CREEK BASIN								
1	Dry Auglaize Creek[2]	NE¼ SE¼ sec. 2, T. 34 N., R. 16 W., at bridge on county highway at northeast edge of Lebanon, Laclede County.	--	6-2-75	1.28	740	22.0	--	--	--	--
				8-25-75	1.31	460	26.0	--			
				11-5-75	.40	610	16.5	--			
				2-24-76	.50	640	9.5	--			
				3-24-76	.02	345	11.5	--			
				8-19-76	.10	--	--	--			

[1]Measurements that are shown were made during seepage runs. Many others are available in files of the U.S. Geological Survey at Rolla, Mo.

[2]Frequency estimates not possible because of variable effect of sewage-treatment plant outflow.

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft³/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft³/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 24, continued)			GRANDGLAIZE CREEK BASIN (continued)								
—	New sewage-treatment plant outfall[2] (first began operating in late February 1976)	SE¼ NE¼ sec. 2, T. 34 N., R. 16 W., at northeast edge of Lebanon, Laclede County.	—	3-24-76	1.20	600	12.5	—	—	—	—
				5-6-76	1.50	600	16.0	—			
				8-19-76	1.60	610	18.0	—			
2	Dry Auglaize Creek[2]	NW¼ NW¼ sec. 31, T. 35 N., R. 15 W., at ford on county highway, 2½ mi northeast of Lebanon, Laclede County.	—	6-2-75	.42	640	22.0	—	—	—	—
				8-25-75	.28	420	25.5	—			
				11-5-75	.90	490	15.5	—			
				2-24-76	.60	520	9.0	—			
				3-24-76	1.90	500	11.5	—			
				5-6-76	2.50	450	17.0	—			
				8-19-76	2.00	500	20.0	—			
3	Dry Auglaize Creek[2]	NW¼ NE¼ sec. 30, T. 35 N., R. 15 W., at ford on county highway, 2 mi southwest of Sleeper, Laclede County.	—	6-2-75	0.51	630	21.0	—	—	—	—
				8-25-75	.04	360	27.0	—			
				11-5-75	1.20	505	15.5	—			
				2-24-76	.80	525	9.0	—			
				3-24-76	2.10	500	11.5	—			
				4-2-76	3.00	430	14.0	—			
				5-6-76	4.50	420	15.5	—			
				11-3-76	1.50	540	15.0	—			
				8-24-77	1.26	650	24.0	23.5			
4	Dry Auglaize Creek[2]	On line between secs. 18 and 19, T. 35 N., R. 15 W., at bridge on county highway, 1½ mi west of Sleeper, Laclede County.	—	6-2-75	0	—	—	—	—	—	—
				8-25-75	0	—	—	—			
				11-5-75	0	—	—	—			
				2-24-76	0	—	—	—			
				3-24-76	.10	450	12.0	—			
				4-2-76	.80	380	8.5	—			
				5-6-76	.50	400	15.5	—			
				8-19-76	0	—	—	—			
				11-3-76	0	—	—	—			
5	Dry Auglaize Creek[3]	SW¼ NW¼ sec. 8, T. 35 N., R. 15 W., at bridge on County Highway F, 2 mi northwest of Sleeper, Laclede County.	—	6-2-75	0.39	294	22.5	—	0	0	0
				8-25-75	0	—	—	—			
				11-5-75	.20	320	16.0	—			
				2-24-76	.20	290	9.5	—			
				3-24-76	.50	230	12.0	—			
				4-2-76	.80	240	11.5	—			
				5-6-76	.60	230	17.0	—			
				8-19-76	0	—	—	—			
				12-21-76	0	—	—	—			
6	Williamson Branch	NW¼ SW¼ sec. 4, T. 35 N., R. 15 W., at ford on county highway, 2½ mi north of Sleeper, Laclede County.	—	6-2-75	0	—	—	—	0	0	0
				8-25-75	0	—	—	—			
				11-5-75	0	—	—	—			
				5-6-76	0	—	—	—			
				8-19-76	0	—	—	—			

[2]Frequency estimates not possible because of variable effect of sewage-treatment plant outflow.

[3]Outflow from sewage-treatment plant is diverted to Niangua River basin through underground solution channels upstream from this site. (See text for details).

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 24, continued)			GRANDGLAIZE CREEK BASIN (continued)								
7	Dry Auglaize Creek	SW¼ SE¼ sec. 29, T. 36 N., R. 15 W., at bridge on county highway, 5 mi west of Stoutland, Laclede County.	---	6-3-75	0	---	---	---	0	0	0
				8-25-75	0	---	---	---			
				11-5-75	0	---	---	---			
				3-24-76	0	---	---	---			
				8-19-76	0	---	---	---			
8	Dry Auglaize Creek	SE¼ SW¼ sec. 19, T. 36 N., R. 15 W., at low-water bridge on County Highway BB, 6½ mi east of Eldridge, Laclede County.	---	6-3-75	0	---	---	---	0	0	0
				11-5-75	0	---	---	---			
				2-24-76	0	---	---	---			
				3-24-76	0	---	---	---			
				8-19-76	0	---	---	---			
9	Dry Auglaize Creek	On line between secs. 13 and 24, T. 36 N., R. 16 W., at low-water bridge on county highway, 6 mi northeast of Eldridge, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				11-5-75	0	---	---	---			
				8-19-76	0	---	---	---			
10	Dry Auglaize Creek	NW¼ SE¼ sec. 14, T. 36 N., R. 16 W., at low-water bridge on county highway, 5 mi northeast of Eldridge, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				8-19-76	0	---	---	---			
11	Goodwin Hollow	NE¼ NE¼ sec. 20, T. 34 N., R. 16 W., at bridge on State Highway 32, 1½ mi southeast of Lebanon, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				8-25-75	0	---	---	---			
				8-20-76	0	---	---	---			
12	Goodwin Hollow	NW¼ SE¼ sec. 4, T. 34 N., R. 16 W., at bridge on State Highway 64, half a mile west of Lebanon, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				8-25-75	0	---	---	---			
				3-26-76	0	---	---	---			
				8-20-76	0	---	---	---			
13	Goodwin Hollow	On line between secs. 28 and 33, T. 35 N., R. 16 W., at bridge on county highway, 3 mi northwest of Lebanon, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				8-25-75	0	---	---	---			
				3-26-76	0	---	---	---			
				8-20-76	0	---	---	---			
14	Goodwin Hollow	NE¼ NW¼ sec. 21, T. 35 N., R. 16 W., at bridge on county highway, 5 mi northwest of Lebanon, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				8-25-75	0	---	---	---			
				8-20-76	0	---	---	---			
15	Goodwin Hollow	SW¼ SW¼ sec. 27, T. 36 N., R. 16 W., at bridge on State Highway 5, 3 mi east of Eldridge, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				8-25-75	0	---	---	---			
				8-20-76	0	---	---	---			
16	Dry Auglaize Creek	On line between secs. 11 and 14, T. 36 N., R. 16 W., at low-water bridge on county highway, 5½ mi northeast of Eldridge, Laclede County.	---	6-2-75	0	---	---	---	0	0	0
				11-5-75	0	---	---	---			
				8-20-76	0	---	---	---			
17	Dry Auglaize Creek	NE¼ NE¼ sec. 35, T. 37 N., R. 16 W., at low-water bridge on county highway, 2½ mi east of Decaturville, Camden County.	---	6-4-75	0	---	---	---	0	0	0
				8-20-76	0	---	---	---			
18	Dry Auglaize Creek	NE¼ SE¼ sec. 22, T. 37 N., R. 16 W., at low-water bridge on county highway, 2 mi northeast of Decaturville, Camden County.	---	6-4-75	0	---	---	---	0	0	0
				8-20-76	0	---	---	---			

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data, Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 24, continued)			GRANDGLAIZE CREEK BASIN (continued)								
19	Pettijohn Hollow	SW¼ SE¼ sec. 14, T. 37 N., R. 16 W., at low-water bridge on county highway, 4 mi southwest of Montreal, Camden County.	---	6-4-75	0	---	---	---	0	0	0
				8-20-76	0	---	---	---			
20	Dry Auglaize Creek	NE¼ SE¼ sec. 35, T. 38 N., R. 16 W., at bridge on State Highway 7, 3½ mi northwest of Montreal, Camden County.	---	5-22-75	3.00	290	21.5	---	0.2	---	---
				6-4-75	1.09	312	23.0	---			
				7-15-75	.38	320	25.5	---			
				11-5-75	1.00	280	15.5	---			
				2-24-76	2.70	300	10.5	---			
				3-24-76	6.50	260	12.5	---			
				5-5-76	4.00	---	---	---			
				7-1-76	.30	280	22.0	---			
				8-20-76	.20	300	23.0	---			
				10-19-76	.17	320	12.0	9.0			
21	Sellers Hollow	NW¼ SW¼ sec. 5, T. 37 N., R. 15 W., at low-water bridge on State Highway 7, 1 mi west of Montreal, Camden County.	---	6-4-75	.14	348	23.5	---	0	0	0
				8-20-76	0	---	---	---			
22	Dry Auglaize Creek	NW¼ SW¼ sec. 17, T. 38 N., R. 15 W., at low-water bridge on county highway, 4 mi north of Montreal, Camden County.	---	5-21-75	0	---	---	---	0	0	0
				6-4-75	0	---	---	---			
				7-15-75	0	---	---	---			
				11-5-75	0	300	19.0	---			
				2-24-76	0	---	---	---			
				10-19-76	0	---	---	---			
23	Dry Auglaize Creek	NW¼ SW¼ sec. 22, T. 38 N., R. 15 W., at low-water bridge on county highway, 2½ mi northeast of Montreal, Camden County.	---	6-4-75	1.53	332	22.0	---	0	0	0
				7-15-75	0	300	17.5	---			
				11-5-75	.60	280	10.0	---			
				2-24-76	1.70	---	---	---			
				8-20-76	0	---	---	---			
				9-9-77	0	---	---	---			
24	Dry Auglaize Creek	NE¼ NW¼ sec. 23, T. 38 N., R. 15 W., at bridge on County Highway A, 2 mi northwest of Toronto, Camden County.	200	5-21-75	4.23	330	28.0	27.0	.4	.1	0
				6-4-75	2.83	368	23.5	---			
				7-15-75	1.14	360	29.0	---			
				11-5-75	1.20	320	19.0	---			
				8-20-76	.50	---	---	---			
				10-19-76	.31	380	11.0	8.0			
				8-23-77	.20	375	30.5	---			
25	Shakerag Creek	NE¼ NE¼ sec. 26, T. 36 N., R. 15 W., at low-water bridge on County Highway H, 1½ mi northwest of Stoutland, Camden County.	---	6-3-75	0	---	---	---	0	0	0
				8-19-76	0	---	---	---			
26	Rocky Hollow	SE¼ SW¼ sec. 1, T. 36 N., R. 15 W., at ford on county highway, 4½ mi north of Stoutland, Camden County.	---	6-3-75	0	---	---	---	0	0	0
				8-19-76	0	---	---	---			
27	Sellars Creek	NE¼ NE¼ sec. 31, T. 37 N., R. 14 W., at bridge on State Highway 7, 6 mi northwest of Richland, Camden County.	20	6-3-75	9.02	370	22.0	---	---	---	---
				8-19-76	4.39	370	23.0	---			
				11-29-77	2.75	---	---	---			

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (μmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 24, continued)			GRANDGLAIZE CREEK BASIN (continued)								
28	Sellars Creek	NE¼ NW¼ sec. 29, T. 37 N., R. 14 W., at low-water bridge on county highway, 5½ mi northwest of Richland, Camden County.	—	6-3-75	9.02	410	27.0	—	—	—	—
				8-19-76	5.75	375	26.0	—			
				5-25-77	4.97	—	—	—			
				11-29-77	5.01	410	5.5	—			
29	Murphy Creek Territory	On line between secs. 10 and 15, T. 36 N., R. 14 W., at bridge on county highway, 2 mi west of Richland, Camden County.	—	6-3-75	0	—	—	—	0	0	0
				8-19-76	0	—	—	—			
				5-25-77	0	—	—	—			
				11-29-77	0	—	—	—			
30	Murphy Creek	NE¼ NW¼ sec. 4, T. 36 N., R. 14 W., at bridge on State Highway 7, 4 mi northwest of Richland, Camden County.	—	6-3-75	0.86	380	21.0	—	0	0	0
				8-19-76	0	—	—	—			
				5-25-77	0	—	—	—			
				11-29-77	0	—	—	—			
31	Wet Glaize Creek	SW¼ SE¼ sec. 17, T. 37 N., R. 14 W., at low-water bridge on county highway, 2½ mi northwest of Wet Glaize, Camden County.	65	5-22-75	13.6	350	21.0	26.0	4.0	2.5	—
				6-3-75	10.5	399	28.5	—			
				7-15-75	6.27	405	24.0	—			
				8-19-76	4.30	362	29.0	—			
				10-20-76	3.79	420	9.5	6.0			
				5-25-77	3.95	—	—	—			
				11-29-77	3.79	405	5.0	—			
32	Mill Creek	SW¼ NW¼ sec. 11, T. 36 N., R. 15 W., at bridge on county highway, 4 mi northwest of Stoutland, Camden County.	—	6-3-75	0	—	—	—	0	0	0
				8-19-76	0	—	—	—			
33	Mill Creek	SW¼ SW¼ sec. 25, T. 37 N., R. 15 W., at bridge on State Highway 7, 4½ mi southeast of Montreal, Camden County.	12	6-3-75	.12	349	29.0	—	0	0	0
				7-15-75	0	—	—	—			
				8-19-76	0	—	—	—			
34	Garman Hollow	SW¼ NE¼ sec. 27, T. 37 N., R. 15 W., at bridge on county highway, 4 mi southeast of Montreal, Camden County.	—	6-3-75	0	—	—	—	0	0	0
				8-19-76	0	—	—	—			
35	Traw Hollow	SE¼ SE¼ sec. 14, T. 37 N., R. 15 W., at bridge on State Highway 7, 3½ mi southeast of Montreal, Camden County.	—	6-3-75	0	—	—	—	0	0	0
				8-19-76	0	—	—	—			
36	Mill Creek	NW¼ SW¼ sec. 18, T. 37 N., R. 14 W., at low-water bridge on county highway, 4 mi southeast of Montreal, Camden County.	32	6-3-75	11.5	339	28.0	—	—	—	—
				8-19-76	4.03	322	30.5	—			
				11-29-77	4.79	—	—	—			
37	Davis Hollow	SE¼ NW¼ sec. 7, T. 37 N., R. 14 W., at low-water bridge on county highway, 5 mi southeast of Montreal, Camden County.	—	6-4-75	0	—	—	—	0	0	0
				8-19-76	0	—	—	—			
38	Wet Glaize Creek	NW¼ NE¼ sec. 6, T. 37 N., R. 14 W., at low-water bridge on county highway, 5 mi northeast of Montreal, Camden County.	113	6-4-75	32.3	372	21.0	—	19	12	11

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 24, continued)		GRANDGLAIZE CREEK BASIN (continued)									
39	Wet Glaize Creek	NE¼ NW¼ sec. 31, T. 38 N., R. 14 W., at bridge on County Highway A, 7 mi south of Brumley, Camden County.	116	5-22-62	35.2	---	---	---	20	12	11
				7-10-62	20.0	---	24.0	---			
				11-13-62	27.2	---	10.0	---			
				9-5-63	17.1	---	---	---			
				10-5-63	14.8	---	18.0	28.0			
				10-6-63	15.2	400	14.0	20.0			
				10-23-64	11.0	430	12.0	16.0			
				9-8-67	16.8	370	21.0	---			
				9-1-70	24.4	380	24.0	35.0			
				10-15-71	24.3	---	15.0	14.5			
				5-22-75	51.9	350	20.0	24.5			
				6-4-75	33.5	389	21.5	---			
				7-15-75	22.0	410	24.0	---			
				8-19-76	16.7	370	28.5	---			
				10-19-76	16.7	420	11.5	7.0			
				8-23-77	19.7	395	25.5	---			
40	Barnett Hollow	NW¼ SE¼ sec. 25, T. 38 N., R. 15 W., at bridge on County Highway A, half a mile south of Toronto, Camden County.	---	6-4-75	0	---	---	---	0	0	0
				8-20-76	0	---	---	---			
				8-23-77	0	---	---	---			
41	Deane Creek	NE¼ NE¼ sec. 34, T. 38 N., R. 14 W., at low-water bridge on county highway, 4½ mi southeast of Toronto, Camden County.	13	6-4-75	.15	422	20.0	---	0	0	0
				2-24-76	2.50	380	10.0	---			
				8-20-76	0	---	---	---			
42	Deane Creek	SE¼ NE¼ sec. 28, T. 38 N., R. 14 W., at low-water bridge on county highway, 3½ mi east of Toronto, Camden County.	20	6-4-75	.37	410	20.5	---	0	0	0
				2-24-76	4.50	370	11.0	---			
				8-20-76	0	---	---	---			
43	Deane Creek	SW¼ SW¼ sec. 20, T. 38 N., R. 14 W., at low-water bridge on county highway, 1½ mi northeast of Toronto, Camden County.	23	6-4-75	2.43	438	22.5	---	0	0	0
				2-24-76	10.0	370	10.5	---			
				8-20-76	0	---	---	---			
44	Deane Creek	NE¼ NE¼ sec. 18, T. 38 N., R. 14 W., at bridge on County Highway C, 3½ mi south of Brumley, Miller County.	30	9-1-70	0	---	---	---	0	0	0
				6-4-75	2.79	426	22.0	---			
				2-24-76	11.0	370	10.0	---			
				8-20-76	0	---	---	---			
45	Brumley Creek	NW¼ sec. 7, T. 38 N., R. 14 W., at mouth, 3½ mi southwest of Brumley, Miller County.	---	7-4-34	0	---	---	---	0	0	0
				7-25-35	5.0	---	---	---			
				9-7-67	0	---	---	---			
				9-10-69	0	---	---	---			
				9-1-70	0	---	---	---			
				9-30-71	0	---	---	---			
				8-20-76	0	---	---	---			
				10-20-76	0	---	---	---			

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft³/s)	Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft³/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 24, continued)			GRANDGLAIZE CREEK BASIN (continued)								
46	Grandglaize Creek	NW¼ sec. 7, T. 38 N., R. 14 W., just downstream from Brumley Creek, 3½ mi southwest of Brumley, Miller County.	360	7-4-34	18.0	—	—	—	29	20	17
				11-2-34	34.7	—	—	—			
				12-28-34	109	—	—	—			
				3-12-35	3,600	—	—	—			
				5-28-35	1,300	—	—	—			
				5-29-35	8,170	—	—	—			
				7-25-35	456	—	—	—			
				7-30-35	75.6	—	—	—			
				10-13-35	34.5	—	—	—			
				12-5-35	38.4	—	—	—			
				1-6-36	33.7	—	—	—			
				4-23-36	40.7	—	—	—			
				4-23-36	36.9	—	—	—			
				6-2-36	23.6	—	—	—			
				7-8-36	16.4	—	—	—			
				9-7-67	26.1	—	—	—			
				9-10-69	60.4	380	18.0	17.5			
				9-1-70	40.5	410	23.0	27.0			
				9-30-71	57.6	360	22.0	26.0			
				6-5-75	69.8	382	22.0	—			
				7-15-75	41.3	420	22.0	—			
				8-20-76	26.8	370	—	—			
				10-20-76	28.3	440	10.5	9.0			
(fig. 23)			OSAGE FORK AND BEAR CREEK BASINS								
1	Osage Fork	NW¼ NW¼ sec. 22, T. 30 N., R. 17 W., at bridge on State Highway 38, 5½ mi southeast of Marshfield, Webster County.	11.2	6-2-75	1.76	370	24.0	—	0.2	0	0
				8-25-75	.08	420	27.5	—			
				11-4-75	2.00	350	16.5	—			
				8-23-76	.50	370	—	—			
				9-16-76	.18	420	21.0	—			
2	Osage Fork Tributary	NE¼ SW¼ sec. 18, T. 30 N., R. 17 W., at bridge on State Highway 38, 2½ mi southeast of Marshfield, Webster County.	3.6	6-2-75	.52	362	22.0	—	0	0	0
				8-25-75	0	—	—	—			
				8-23-76	.10	370	21.0	—			
				9-16-76	.04	390	23.0	—			
3	Osage Fork	On line between secs. 5 and 8, T. 30 N., R. 17 W., at bridge on County Highway DD, 3 mi east of Marshfield, Webster County.	32.4	6-2-75	5.14	382	25.5	—	.5	0	0
				8-25-75	.34	405	29.0	—			
				11-4-75	9.00	350	16.5	—			
				8-23-76	1.40	355	22.0	—			
				9-16-76	.16	400	22.0	—			
4	Osage Fork	SE¼ NE¼ sec. 33, T. 31 N., R. 17 W., at low-water bridge on county highway, 5½ mi northeast of Marshfield, Webster County.	40	6-2-75	6.75	400	25.0	—	0.5	0	0
				8-25-75	.34	360	31.0	—			
				11-4-75	13.0	355	16.0	—			
				8-23-76	1.90	335	22.5	—			
				9-16-76	.11	370	24.0	—			

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 23, continued)			OSAGE FORK AND BEAR CREEK BASINS (continued)								
5	Osage Fork	SE¼ SE¼ sec. 22, T. 31 N., R. 17 W., at bridge on County Highway M, 2½ mi east of Niangua, Webster County.	43	9-17-53	.02	--	23.0	--	.5	.1	0
				6-3-75	11.4	400	21.0	--			
				8-25-75	.48	395	30.5	--			
				11-4-75	18.5	365	15.5	--			
				8-23-76	2.00	350	24.0	--			
				9-16-76	.13	380	24.0	--			
6	Cantrell Creek	NE¼ NE¼ sec. 30, T. 31 N., R. 16 W., at bridge on County Highway M, 5½ mi east of Niangua, Webster County.	32	7-17-53	.10	--	--	--	1.4	.6	--
				6-3-75	10.6	365	19.5	--			
				8-25-75	1.01	380	29.5	--			
				2-26-76	8.00	360	14.0	--			
				8-23-76	2.00	340	26.0	--			
				9-16-76	.79	--	23.0	--			
7	Hyde Creek	SW¼ NW¼ sec. 28, T. 31 N., R. 16 W., at bridge on County Highway M, 7 mi east of Niangua, Webster County.	18	9-17-53	0.02	--	--	--	0.1	--	--
				6-3-75	3.87	325	18.0	--			
				8-25-75	.15	420	27.5	--			
				2-26-76	2.00	340	14.0	--			
				8-23-76	.20	--	--	--			
				9-16-76	.06	370	26.0	--			
8	Cantrell Creek	SE¼ SE¼ sec. 12, T. 31 N., R. 17 W., at low-water bridge on county highway, 4½ mi northeast of Niangua, Webster County.	62	5-20-75	17.6	370	23.0	23.0	1.1	0.4	--
				6-3-75	18.2	400	21.5	--			
				7-17-75	2.51	420	27.0	--			
				2-26-76	11.0	360	12.0	--			
				8-23-76	1.26	320	23.0	--			
				9-16-76	.39	390	24.0	--			
				10-18-76	1.27	400	11.0	11.5			
9	Osage Fork	SE¼ SW¼ sec. 12, T. 31 N., R. 17 W., at low-water bridge on County Highway F, 4½ mi northeast of Niangua, Webster County.	117	6-3-75	29.6	405	23.0	--	1.8	.6	--
				8-23-76	4.00	345	26.0	--			
				9-16-76	.66	380	24.0	--			
10	Bowen Creek	NE¼ SW¼ sec. 2, T. 31 N., R. 17 W., at ford on county highway, 4 mi northeast of Niangua, Webster County.	8.0	6-3-75	2.07	413	25.0	--	0.1	--	--
				8-23-76	.10	365	28.0	--			
				9-17-76	.07	420	21.0	--			
11	Little Bowen Creek	SE¼ NW¼ sec. 2, T. 31 N., R. 17 W., at ford on county highway, 4 mi northeast of Niangua, Webster County.	8.0	6-3-75	.46	395	24.0	--	.1	--	--
				8-23-76	.10	--	--	--			
				9-12-76	.02	400	20.0	--			
12	Osage Fork	NW¼ NE¼ sec. 2, T. 31 N., R. 17 W., at low-water bridge on county highway, 3½ mi southwest of Rader, Webster County.	136	6-3-75	28.8	438	23.5	--	2.5	.8	--
				8-23-76	3.30	350	--	--			
				9-17-76	.94	370	20.0	--			
13	Myers Branch	NW¼ SW¼ sec. 29, T. 32 N., R. 16 W., at low-water bridge on County Highway N at Rader, Webster County.	9.4	6-3-75	1.21	370	22.0	--	0	0	0
				8-23-76	0	--	--	--			
				9-17-76	0	410	20.0	--			
				10-18-76	0	--	--	--			

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi²)	Date	Streamflow data: Discharge (ft³/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft³/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 23, continued)			OSAGE FORK AND BEAR CREEK BASINS (continued)								
14	Osage Fork	SE¼ NE¼ sec. 30, T. 32 N., R. 16 W., at bridge on County Highway ZZ at Rader, Webster County.	154	9-28-71	9.16	380	23.5	24.0	2.4	0.3	---
				8-31-72	2.46	390	24.0	---			
				5-20-75	39.3	360	25.5	27.0			
				6-3-75	30.5	420	24.0	---			
				7-17-75	7.41	410	27.0	---			
				9-9-75	10.2	380	24.0	---			
				8-23-76	2.95	350	23.0	---			
				9-17-76	.50	380	---	---			
				10-18-76	2.59	390	12.5	15.0			
				5-24-77	8.86	---	23.5	---			
				8-25-77	13.1	380	25.0	---			
15	Osage Fork	On line between secs. 16 and 17, T. 32 N., R. 16 W., at low-water bridge on county highway, 2 mi southwest of Morgan, Laclede County.	180	6-4-75	37.7	360	22.0	---	4.0	1.5	---
				8-23-76	6.00	---	---	---			
				9-17-76	1.92	390	22.0	25.0			
16	Osage Fork	NE¼ SE¼ sec. 16, T. 32 N., R. 16 W., at low-water bridge on county highway, 1½ mi south of Morgan, Laclede County.	185	6-4-75	38.5	360	21.5	---	5.0	2.0	---
				8-23-76	7.20	---	---	---			
				9-17-76	2.45	370	22.0	---			
17	Osage Fork	SE¼ SW¼ sec. 14, T. 32 N., R. 16 W., at bridge on county highway, 1½ mi southeast of Morgan, Laclede County.	196	6-4-75	45.3	388	23.5	---	5.8	2.4	---
				8-23-76	7.90	340	23.0	---			
				9-17-76	2.94	390	23.0	---			
18	Osage Fork	NW¼ SW¼ sec. 7, T. 32 N., R. 15 W., at bridge on County Highway Y, 2 mi southeast of Morgan, Laclede County.	199	9-17-53	1.87	---	22.0	---	6.5	2.5	---
				9-1-54	3.14	---	27.0	---			
				9-20-71	26.1	350	20.0	---			
				4-18-72	228	310	20.0	---			
				9-6-72	6.68	360	23.0	26.0			
				11-15-72	698	250	9.0	1.0			
				6-4-75	43.2	390	24.5	---			
				8-24-76	8.07	345	23.0	---			
				9-17-76	4.53	380	22.0	28.0			
19	Parks Creek	SE¼ SW¼ sec. 7, T. 32 N., R. 15 W., at bridge on County Highway Y, 2½ mi southeast of Morgan, Laclede County.	36	9-17-53	.03	---	---	---	.2	.04	---
				6-4-75	3.94	335	22.0	---			
				11-6-75	2.80	325	18.5	---			
				8-24-76	.70	350	23.0	---			
20	Big Spring[1]	NE¼ NE¼ sec. 6, T. 32 N., R. 15 W., in bed of Osage Fork about 3 mi northeast of Morgan, Laclede County.	---	---	---	---	---	---	19	14	---
21	Osage Fork	SW¼ SE¼ sec. 31, T. 33 N., R. 15 W., at low-water bridge on county highway, 2½ mi northeast of Morgan, Laclede County.	243	9-17-53	19.4	---	17.0	---	27	17	---
				7-13-54	18.3	---	---	---			
				9-1-54	19.7	---	19.0	---			
				6-4-75	87.8	375	18.5	---			
				8-24-76	26.3	365	17.0	---			
22	Brush Creek	NE¼ NW¼ sec. 36, T. 33 N., R. 16 W., at low-water bridge on county highway, 2 mi northeast of Morgan, Laclede County.	37.7	6-4-75	2.08	332	22.0	---	---	---	---
				8-24-76	.50	345	20.0	---			

[1]Measurements that are shown were made during seepage runs. Many others are available in files of the U.S. Geological Survey at Rolla, Mo.

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Streamflow data: Date	Discharge (ft^3/s)	Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 23, continued)			OSAGE FORK AND BEAR CREEK BASINS (continued)								
23	Osage Fork	NW¼ NW¼ sec. 33, T. 33 N., R. 15 W., at bridge on State Highway 5, 3 mi west of Orla, Laclede County.	287	9-17-53	16.9	--	18.0	--	25	15	11
				10-12-61	32.6	--	--	--			
				5-21-62	89.4	--	--	--			
				8-2-62	31.9	--	23.0	--			
				9-3-63	19.8	--	25.0	--			
				9-30-63	18.5	--	14.0	--			
				11-4-63	19.0	360	12.0	--			
				10-20-64	20.4	390	13.0	14.0			
				9-5-67	22.8	370	19.0	--			
				8-31-70	26.6	380	22.0	25.5			
				9-27-71	37.2	370	24.0	26.0			
				5-20-75	122	330	20.0	23.5			
				6-4-75	94.1	382	21.5	--			
				7-17-75	40.7	400	22.0	--			
				8-24-76	24.2	365	20.0	--			
				10-18-76	20.4	400	10.0	10.5			
24	Osage Fork	On line between secs. 25 and 26, T. 33 N., R. 15 W., at bridge on county highway at Orla, Laclede County.	297	6-4-75	90.8	370	22.5	--	25	15	11
				8-24-76	23.4	350	23.0	--			
25	Steins Creek	NE¼ NE¼ sec. 10, T. 32 N., R. 15 W., at ford on County Highway O, 2 mi southeast of Orla, Laclede County.	40	11-6-75	1.20	360	17.5	--	0.2	0	0
				2-26-76	1.30	340	15.5	--			
				7-2-76	1.00	--	--	--			
				8-24-76	.10	--	--	--			
				3-7-77	.20	--	--	--			
				9-9-77	.05	--	--	--			
26	Steins Creek	NW¼ NW¼ sec. 36, T. 33 N., R. 15 W., at bridge on county highway, half a mile southeast of Orla, Laclede County.	50	9-17-53	0	--	--	--	0	0	0
				6-4-75	0	--	--	--			
				11-6-75	0	--	--	--			
				2-26-76	0	--	--	--			
				7-2-76	0	--	--	--			
				3-7-77	0	--	--	--			
				9-9-77	0	--	--	--			
27	Osage Fork	SE¼ NW¼ sec. 7, T. 33 N., R. 14 W., at bridge on County Highway B, 4 mi northeast of Orla, Laclede County.	356	6-5-75	95.4	362	22.5	--	25	15	11
				8-24-76	24.1	362	25.0	--			
28	Osage Fork	NE¼ NW¼ sec. 16, T. 33 N., R. 14 W., at bridge on county highway, 4½ mi northeast of Orla, Laclede County.	--	8-24-76	26.0	360	25.5	--	--	--	--
29	Cobb Creek	SE¼ NW¼ sec. 21, T. 33 N., R. 14 W., at bridge on County Highway B, 4 mi northeast of Orla, Laclede County.	15	11-6-75	1.5	360	16.0	--	0	0	0
				8-24-76	0	--	--	--			
30	Little Cobb Creek	SW¼ NE¼ sec. 22, T. 33 N., R. 14 W., at bridge on county highway, 5 mi northeast of Orla, Laclede County.	8.8	11-6-75	.2	340	16.5	--	0	0	0
				8-24-76	0	--	--	--			

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (µmho/cm at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 23, continued)			OSAGE FORK AND BEAR CREEK BASINS (continued)								
31	Osage Fork[1]	NW¼ NE¼ sec. 27, T. 34 N., R. 14 W., at bridge on State Highway 32, 0.6 mi southeast of Drynob, Laclede County. (Continuous-record station).	404	5-20-75	165	—	—	—	27	16	12
				6-5-75	106	—	—	—			
				7-17-75	50.9	370	25.0	—			
				8-24-76	30.0	—	—	—			
32	Core Creek	SE¼ NE¼ sec. 23, T. 34 N., R. 14 W., at low-water bridge on county highway, 1 mi east of Drynob, Laclede County.	—	6-5-75	0	—	—	—	0	0	0
				8-24-76	0	—	—	—			
33	North Cobb Creek	NE¼ NW¼ sec. 28, T. 34 N., R. 14 W., at bridge on State Highway 32, 1½ mi west of Drynob, Laclede County.	52.0	5-20-75	3.84	320	21.5	24.5	.2	—	—
				6-5-75	4.06	340	24.0	—			
				7-17-75	.98	360	24.5	—			
				11-6-75	4.30	345	16.0	—			
				2-26-76	3.50	320	12.5	—			
				8-24-76	.10	—	—	—			
				10-18-76	.28	380	7.5	7.0			
34	Osage Fork	SW¼ NE¼ sec. 17, T. 34 N., R. 14 W., at bridge on County Highway AC, 8½ mi east of Lebanon, Laclede County.	—	6-5-75	118	365	23.5	—	—	—	—
35	Osage Fork	SE¼ NE¼ sec. 5, T. 34 N., R. 14 W., at low-water bridge on county highway, 8 mi east of Lebanon, Laclede County.	—	8-24-76	28.8	342	25.5	—	—	—	—
36	Mill Creek	SW¼ NE¼ sec. 5, T. 34 N., R. 14 W., at bridge on County Highway N, 8 mi east of Lebanon, Laclede County.	15.6	6-5-75	1.07	360	23.0	—	0	0	0
				8-24-76	0	—	—	—			
37	Gasconade River	SE¼ NE¼ sec. 23, T. 35 N., R. 14 W., at low-water bridge on county highway, 1½ mi southwest of Hazelgreen, Laclede County. (Upstream from mouth of Osage Fork).	—	6-6-75	210	360	25.0	—	—	—	—
38	Gasconade River[1]	SE¼ SE¼ sec. 15, T. 35 N., R. 14 W., at bridge on Interstate Highway 44, 1½ mi west of Hazelgreen, Laclede County. (Continuous-record at this site 1928-71).	1,250	6-6-75	332	363	25.0	—	66	30	25
				7-17-75	140	330	25.0	—			
				8-26-76	65.0	—	—	—			
				10-20-76	57.6	395	9.5	4.0			
39	Bear Creek	SW¼ NE¼ sec. 5, T. 34 N., R. 15 W., at bridge on County Highway MM, 2½ mi northeast of Lebanon, Laclede County.	—	6-5-75	0	—	—	—	0	0	0
				3-25-76	0	—	—	—			
40	Bear Creek	NW¼ NE¼ sec. 28, T. 35 N., R. 15 W., at bridge on outer road of Interstate Highway 44, 1 mi south of Sleeper, Laclede County.	—	6-5-75	0	—	—	—	0	0	0
				3-25-76	0	—	—	—			
41	Bear Creek	SW¼ SW¼ sec. 18, T. 35 N., R. 15 W., at bridge on county highway, 4 mi south of Stoutland, Laclede County.	—	6-5-75	.21	365	25.5	—	0	0	0
				3-25-76	2.80	330	15.0	—			
				8-24-76	0	—	—	—			
				9-18-76	0	—	—	—			

[1]Measurements that are shown were made during seepage runs. Many others are available in files of the U.S. Geological Survey at Rolla, Mo.

Table 6 (continued)

Map no.	Stream name	Location	Drainage area (mi^2)	Date	Streamflow data: Discharge (ft^3/s)	Streamflow data: Specific conductance (μmho/cm) at 25°C)	Water temperature (°C)	Air temperature (°C)	Low-flow frequency data: Annual low-flow (in ft^3/s) for 7 consecutive days at indicated recurrence interval (in years): 2	10	20
(fig. 23, continued)			OSAGE FORK AND BEAR CREEK BASINS (continued)								
42	Bear Creek	SW¼ SE¼ sec. 7, T. 35 N., R. 14 W., at bridge on county highway, 2½ mi south of Stoutland, Laclede County.	—	3-25-76	5.50	340	14.5	—	.2	0	0
				8-24-76	.10	—	26.0	—			
				9-10-76	.20	460	22.0	—			
43	Bear Creek	SW¼ NE¼ sec. 5, T. 35 N., R. 14 W., at bridge on County Highway T, 1½ mi southeast of Stoutland, Laclede County.	—	6-6-75	0	—	—	—	0	0	0
				3-25-76	0	—	—	—			
				8-24-76	0	—	—	—			
44	Bear Creek	SW¼ SW¼ sec. 36, T. 36 N., R. 14 W., at low-water bridge on County Highway FF, 3 mi southwest of Richland, Laclede County.	—	6-6-75	0.38	405	23.0	—	0.05	0	0
				3-25-76	1.00	340	15.0	—			
				8-24-76	.05	—	—	—			
				9-10-76	.05	—	—	—			
				10-20-76	.08	—	—	—			
				9-9-77	.02	—	—	—			
45	Bear Creek	NW¼ NE¼ sec. 6, T. 35 N., R. 13 W., at bridge on State Highway 133, 3½ mi south of Richland, Pulaski County.	43	5-22-75	1.50	360	24.0	30.5	0	0	0
				6-6-75	.29	400	21.0	—			
				7-17-75	0	—	—	—			
				3-25-76	.90	340	15.0	—			
				8-24-76	0	—	—	—			
				10-20-76	0	—	—	—			

A new sewage-treatment plant for Lebanon began operation in February 1976, in the upper reaches of the basin. The plant, with an average discharge of about 1.1 mgd (million gallons per day), replaced two facilities active for some years on Dry Auglaize Creek and Goodwin Hollow (fig. 24). In the project area, this reach of Dry Auglaize Creek is the only place where urban effects on streamflow are significant. Because of variable discharges from the sewage-treatment plant, frequency estimates could not be shown for several stations in the upper reaches of Dry Auglaize Creek (table 6).

SEEPAGE RUNS

Data from seepage runs are among the best sources of information concerning magnitude and distribution of low flows and anomalies within and among stream basins. If several flow measurements are made at seepage-run sites during the course of an investigation, the data can also be used to estimate low-flow frequency characteristics at those sites (plate 13). Seepage runs in small areas (figs. 25 to 28) are of special interest, because data collected from them can be used in studying the interrelation between groundwater and surface water.

Most of the seepage-run data were collected during periods of minimum streamflow in the summer and fall, but data collected in the winter and spring (during periods when there is no storm runoff) can supply valuable information about areas of significant water loss in normally dry channels. In many cases, streams that lose flow to bedrock will still be dry during the winter and spring "wet" seasons, whereas streams that are

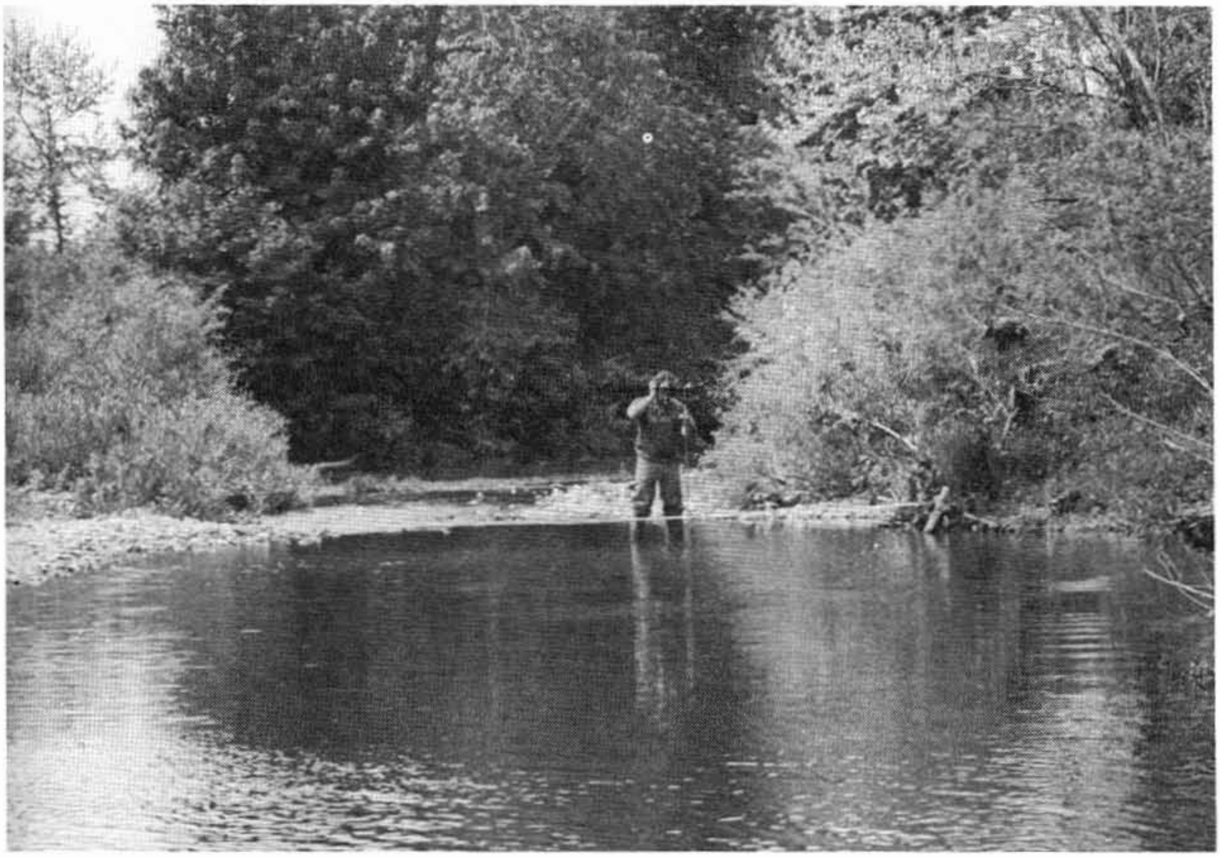


Plate 13. Taking stream-flow measurements along Mill Creek, sec. 36, T. 37 N., R. 15 W., Camden County, as part of a seepage run to determine stream losses or gains. Photograph by James E. Vandike.

normally dry during hot, rainless periods of high evapotranspiration will be flowing. Discharge measurements in the flowing reaches can pinpoint zones of water loss that would be otherwise unnoted; these zones can be related to geologic and structural features, vegetation, topography and slope, and groundwater levels.

Conclusions based on seepage-run data are as follows:

1. Big Spring, near Morgan (fig. 23), contributes about 60 percent of the flow of Osage Fork during low base-flow conditions and about 40 percent during high base-flow conditions.
2. Bennett Spring, at Bennett Spring State Park (fig. 22), contributes about 60 percent of the flow of the Niangua River during low base-flow conditions and about 50 percent during high base-flow conditions.
3. The Osage Fork basin contains more tributaries with base flow during most of the year than either the Niangua River or Grandglaize Creek basins. The greater number of dry tributaries in the latter two suggests that more of the precipitation falling in these basins is stored, to be discharged later and at a more uniform rate from the several large springs along the main stems.

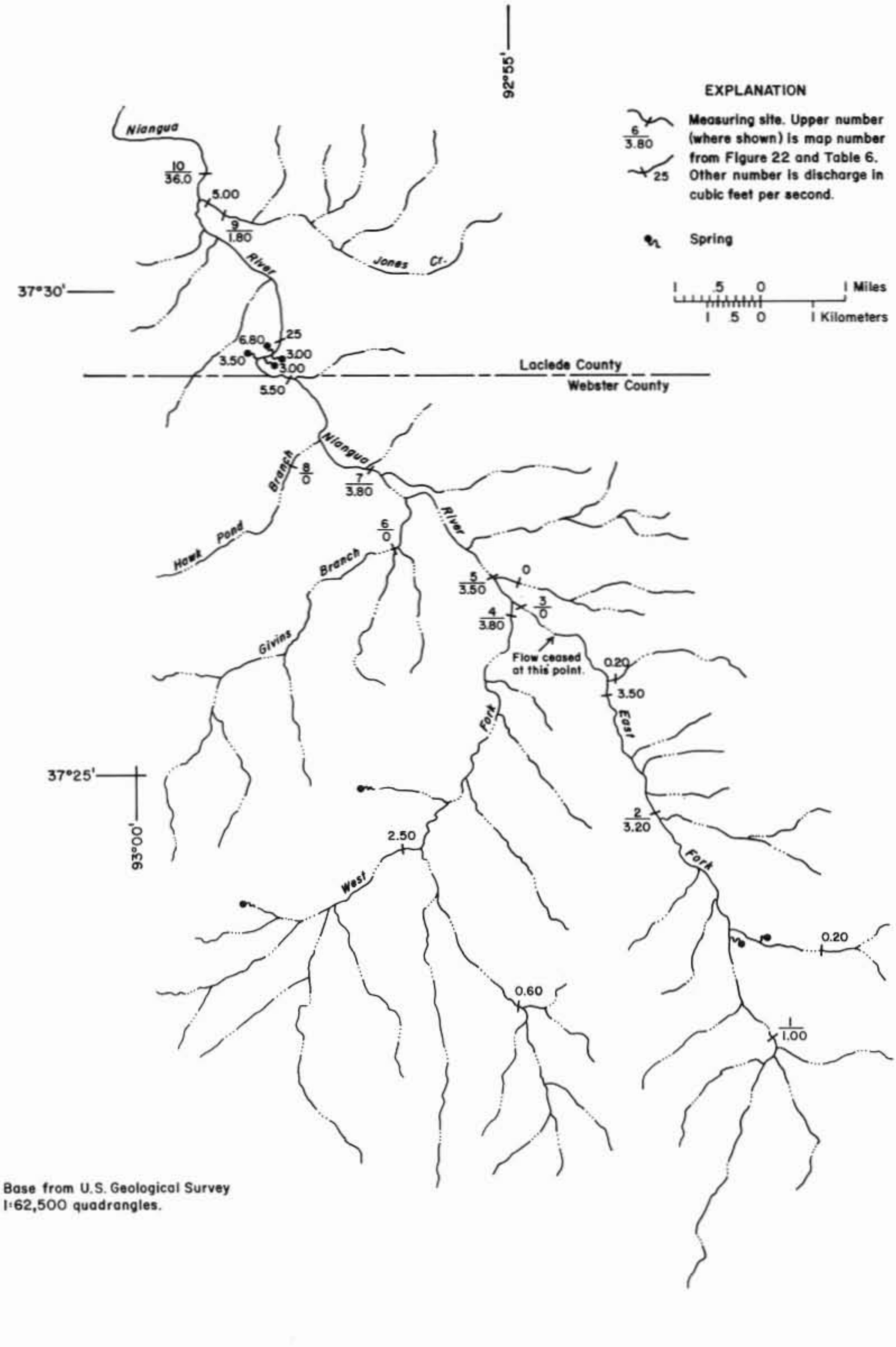


Figure 25. Seepage-run measurements in the upper Niangua River basin, November 11-12, 1975.

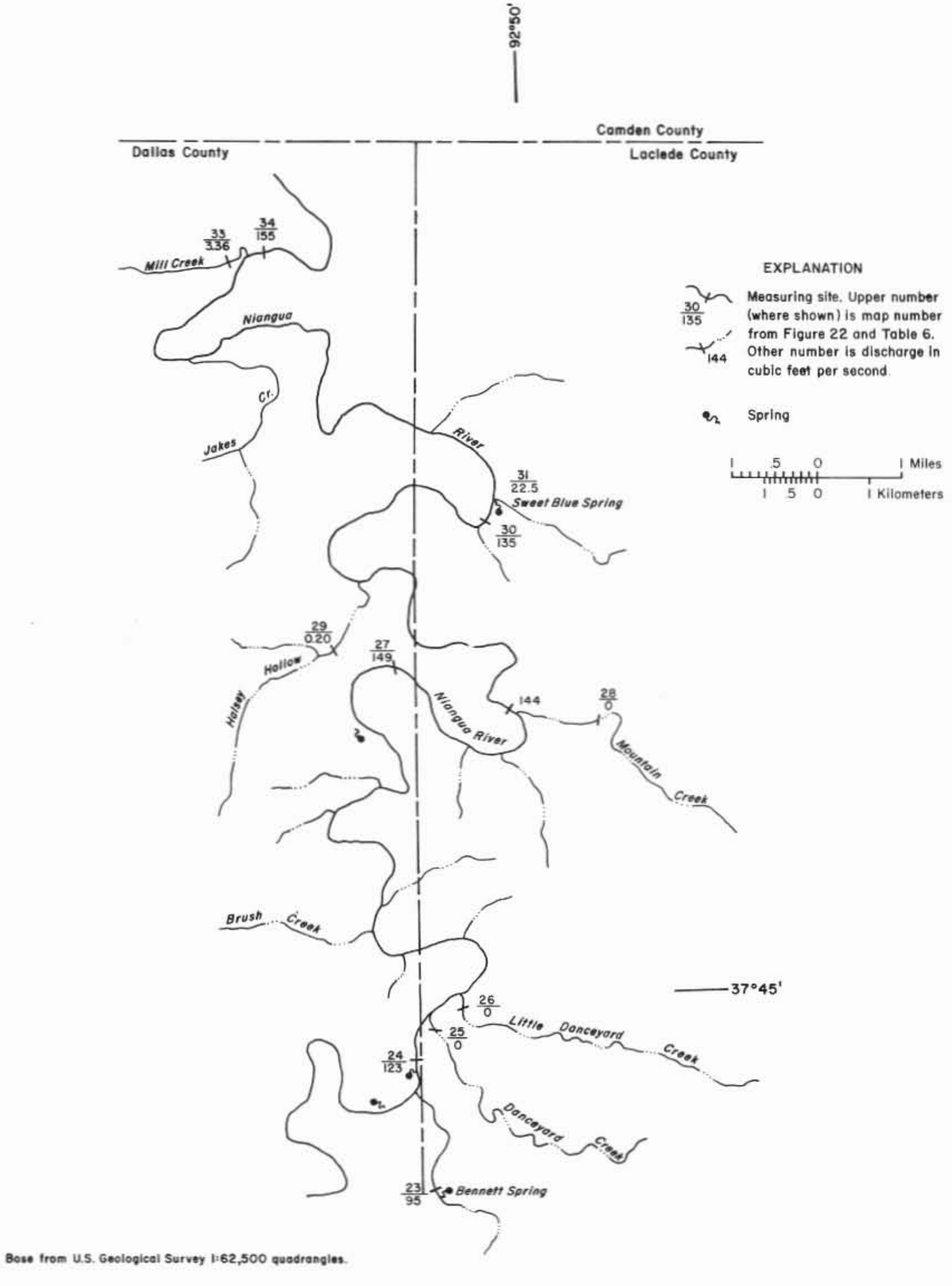


Figure 26. Seepage-run measurements in the lower Niangua River basin, August 25-26, 1976.

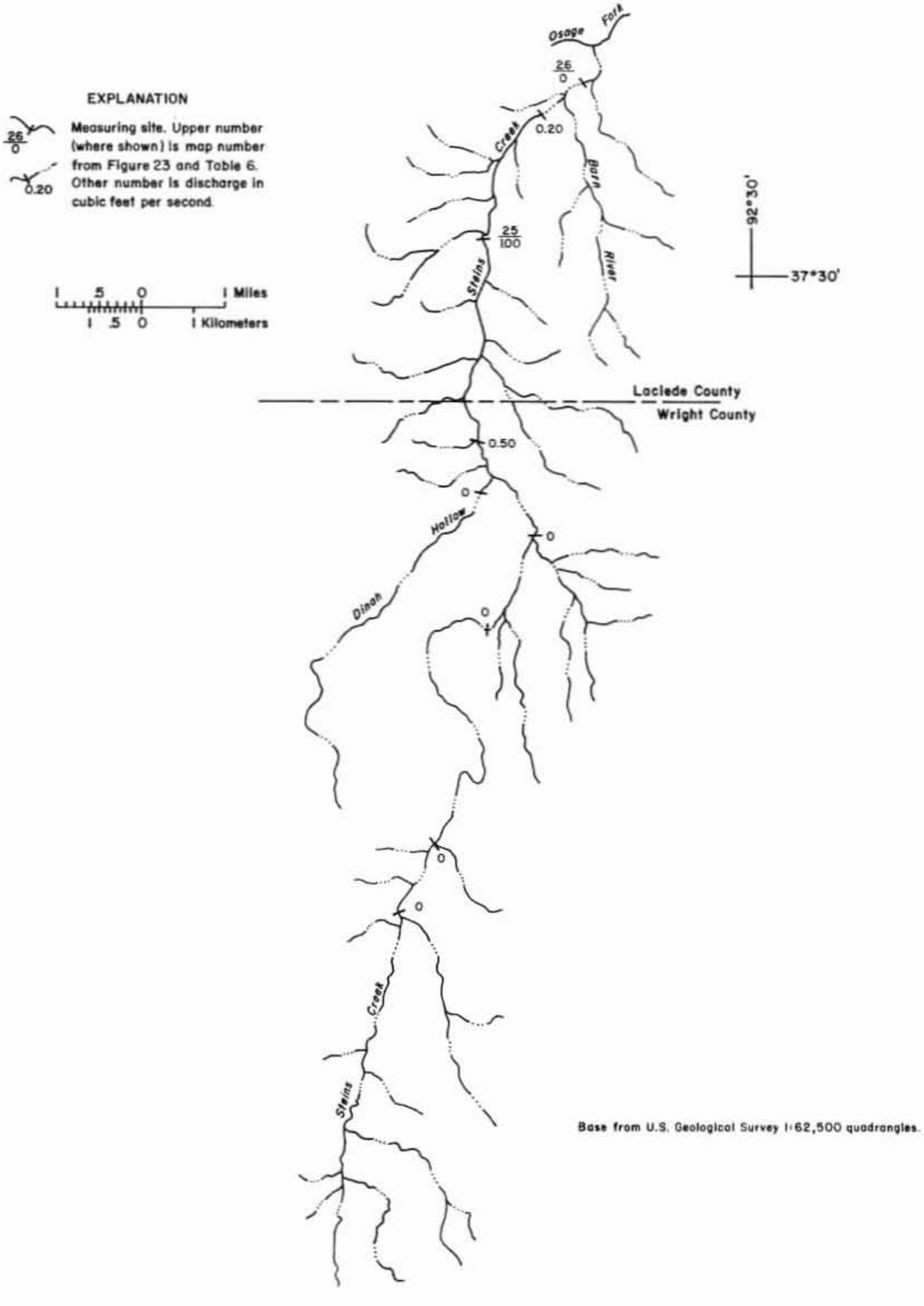


Figure 27. Seepage-run measurements in the Steins Creek basin, July 2, 1976.

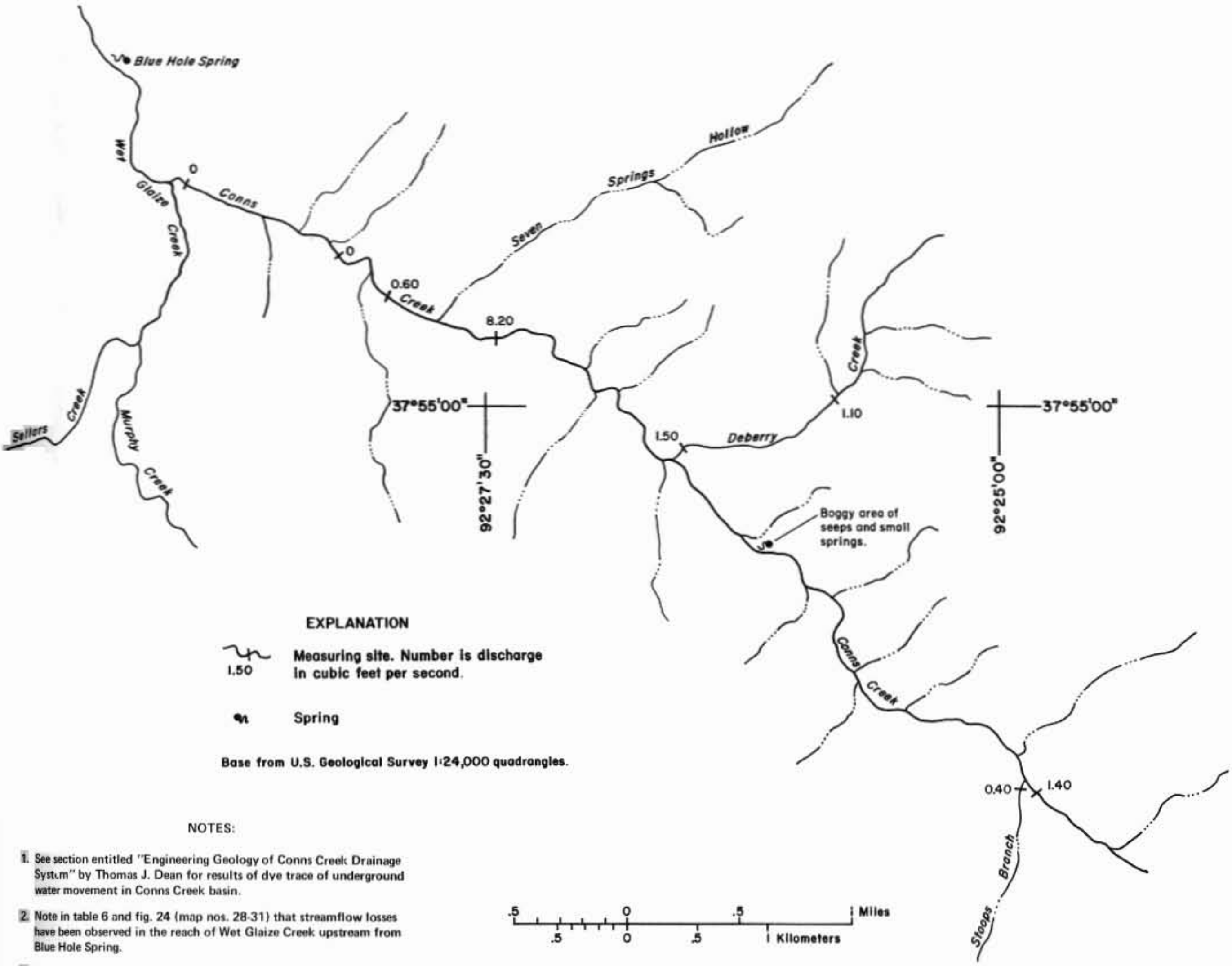


Figure 28. Seepage-run measurements in the Conns Creek basin, April 1, 1976.

Stream name	Tributary contribution (percent)	Known springs contribution (percent)	Contributions along main stem	Total flow (percent)
		High base flow, June 1975		
Osage Fork	27	36	37	100
Niangua River	8	62	30	100
		Low base flow, August 1976		
Osage Fork	11	61	28	100
Niangua River	4	68	28	100

4. The tributaries contribute only a small proportion of the total base flows of the main stems; most of the water is contributed along the valleys by springs. The preceding table shows the proportions of total flows contributed by tributaries, known springs, upwelling of groundwater in the bed of the streams, groundwater discharge from any alluvial fills bordering streams, and along the main stems by small springs that have not been inventoried. Flow and increments of groundwater discharge are much better sustained along the Niangua River than along the Osage Fork, because, in the case of the former, more precipitation is stored, to be discharged at a more even rate throughout the year.

5. Streams draining the Jefferson City Dolomite often lose their flow shortly after reaching the Roubidoux Formation. Once the zone of saturation has been intersected by the stream valleys, however, larger base flows can be expected from the Roubidoux Formation than from the Jefferson City and Cotter Dolomites, because the Roubidoux is topographically lower and has greater storage capacity.

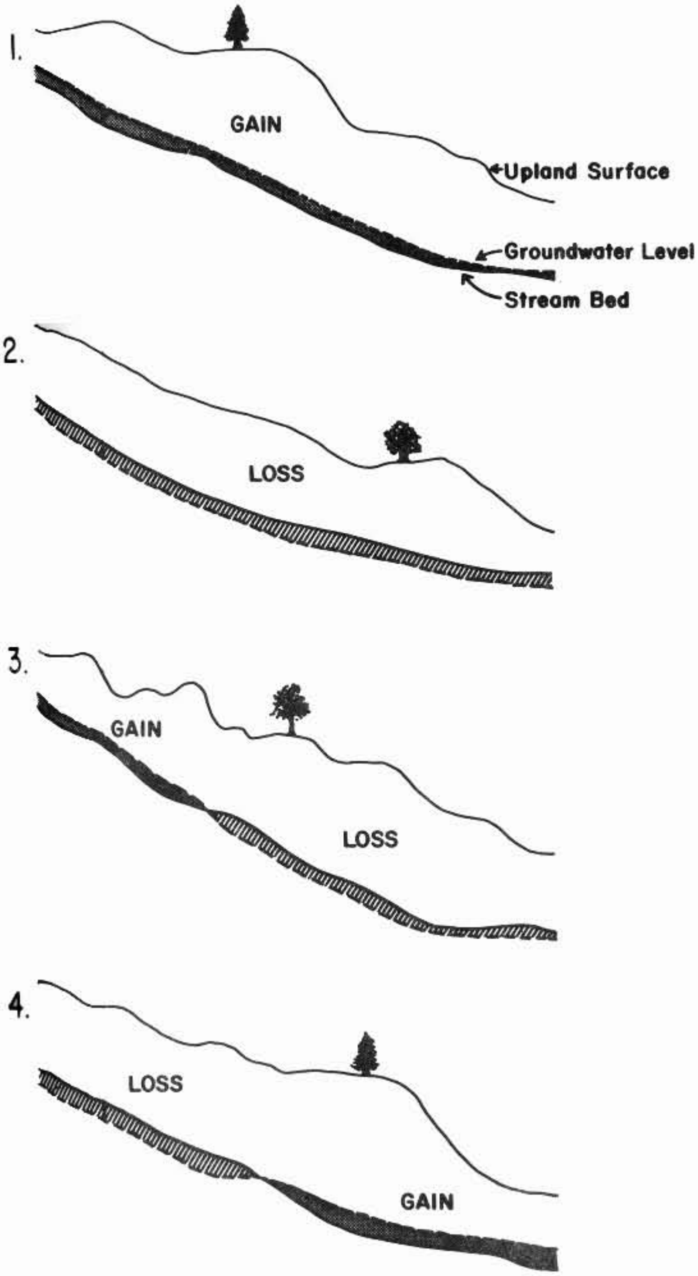
6. Discharges of principal streams increase markedly when they enter the Gasconade Dolomite if the zone of saturation intersects the valleys. In a few places where streams cross the formation, however, there is flow only after heavy rains.

CLASSIFICATION AND DESCRIPTION OF STREAMS

On the basis of continuity of flow (fig. 29), streams in the project area and in other areas of carbonate-rock terrane can be divided into four types:

Type 1 streams are characterized as gaining from headwaters to mouth; this does not imply, however, that they will flow continuously during the year. Evapotranspiration may deplete the water in storage, so that none is left for streamflow, but groundwater levels will be shallow beneath the valley; Broadus Branch in the Niangua basin is an example. Two reaches along the Osage Fork and one on the lower Niangua River have small decreases in flow at low stages. Decreases are small compared to total flows, however, and are considered diversions through bedrock channels to downstream points of discharge; for this reason, the two rivers are classified Type 1.

Type 2 streams have low water levels throughout their lengths and generally do



Type No.	Stream Name	Basin
1.	West Fork Niangua River	Niangua
	Osage Fork	Osage Fork
	Broadus Branch	Niangua
	Jugtown Hollow	Niangua
	Niangua River	Niangua
2.	Mountain Creek	Niangua
	Four Mile Creek	Niangua
	Barnett Hollow	Wet Glaize
	Cave Creek	Niangua
	Woolsey Creek	Niangua
	Hawk Pond Creek	Niangua
	Givins Branch	Niangua
	Traw Hollow	Wet Glaize
3.	Jones Creek	Niangua
	Bennett Spring Creek	Niangua
	Dry Auglaize Creek	Wet Glaize
	Steins Creek	Osage Fork
	Conns Creek	Wet Glaize
	East Fork Niangua River	Niangua
	Goodwin Hollow	Wet Glaize
	Deberry Creek	Wet Glaize
	Parks Creek	Osage Fork
4.	Brush Creek	Osage Fork
	Centrell Creek	Osage Fork
	Garman Hollow	Wet Glaize
	Wet Glaize Creek	Wet Glaize
	Panther Creek	Osage Fork
	Hyde Creek	Osage Fork
	Bowen Creek	Osage Fork
	Little Bowen Creek	Osage Fork
	North Cobb Creek	Osage Fork
	Cobb Creek	Osage Fork
	Little Cobb Creek	Osage Fork
	Dousinbury Creek	Niangua
	Mill Creek – Niangua	Niangua
	Jakes Creek	Niangua
	Halsey Hollow	Niangua
	Durington Creek	Niangua
	Indian Creek	Niangua
	Deane Creek	Wet Glaize
	Mill Creek	Wet Glaize
	Greasy Creek	Niangua
	Banks Creek	Niangua
	Spencer Creek	Niangua
	Myers Branch	Osage Fork
	Smith Branch	Osage Fork
	Core Creek	Osage Fork
	Bear Creek	Gasconade
	Murphy Creek	Wet Glaize
	Mill Creek	Osage Fork

Figure 29. Flow patterns of streams based on continuity of flow.

not flow in any reach except after heavy rains; Mountain Creek in the Niangua River basin is an example.

Type 3 streams are characterized by an upstream gaining reach followed by a losing reach, a pattern that may be repeated several times in some streams. For example, Dry Auglaize Creek has four gaining reaches alternating with four losing reaches. The lengths of each segment in a particular stream vary, so that the upstream gaining reach may extend far downstream or for only a short distance.

Most of the streams are Type 4, in which the upper part of the basin is a losing reach followed by a gaining reach. The upper part is considered a recharge area, and the zone of saturation is below the stream channel, which is dry except after rain. At some point downstream, the zone of saturation intersects the level of the flood plain and flow begins. As in Type 3 streams, the pattern may be repeated several times. Because of the potential of unsaturated storage in the flood plain of a receiving stream, surface flow may disappear when small tributary streams reach the flood plain of the receiving stream.

WATER QUALITY OF STREAMS AND SPRINGS

A good understanding of movement of water through the flow system of carbonate rocks aids in identifying sources of pollution and areas where wells, springs, and streams may be affected; hence, dye traces, seepage runs, geologic mapping, and water-level contouring contribute to the interpretation of water-quality data and determination of sites where repetitive sampling would be useful to verify anomalous values.

All water in the system, whether well water, springflow, or streamflow, is of the calcium-magnesium-bicarbonate type. Sodium, potassium, sulfates, and chlorides are present in small amounts. During a base-flow period, bacterial counts were measured and chemical-quality samples taken at seven springs and nine streamflow sites (fig. 30 and table 7).

Fecal coliform and fecal streptococcus counts for springs were lower than those for streams, but counts for both springs and streams were not inordinately high. The moderately high counts for Dry Auglaize Creek, near Sleeper, are due to effluent, which accounts for most of the flow, from the sewage-treatment plant at Lebanon. A short distance downstream from the sampling point, the creek goes underground and the water reappears in Sweet Blue and Hahatonka Springs (Skelton and Miller, 1979). Dilution by groundwater and bacteria die-off reduce the concentration in the springflow, so that counts are no higher than those of other sampled area springs.

It is difficult to account for the pollution of Dry Auglaize Creek at Toronto (fig. 30, map no. 15), as few people live in the valley or on the adjacent uplands, and the stream begins to flow only about 3.5 mi upstream. A possible source is an area near Montreal, about 4 mi southwest of the site, which contains a rather unusual cluster of broad sinkholes, where a number of families operate turkey farms. The cluster is unusual, because few sinks occur within miles of this locality. Wastes from septic tanks and turkey farms can be carried down through the sinkholes, but northwest-trending faults suggest a more likely route, parallel to the fault system. On the other hand, if a northeast-oriented system of intense

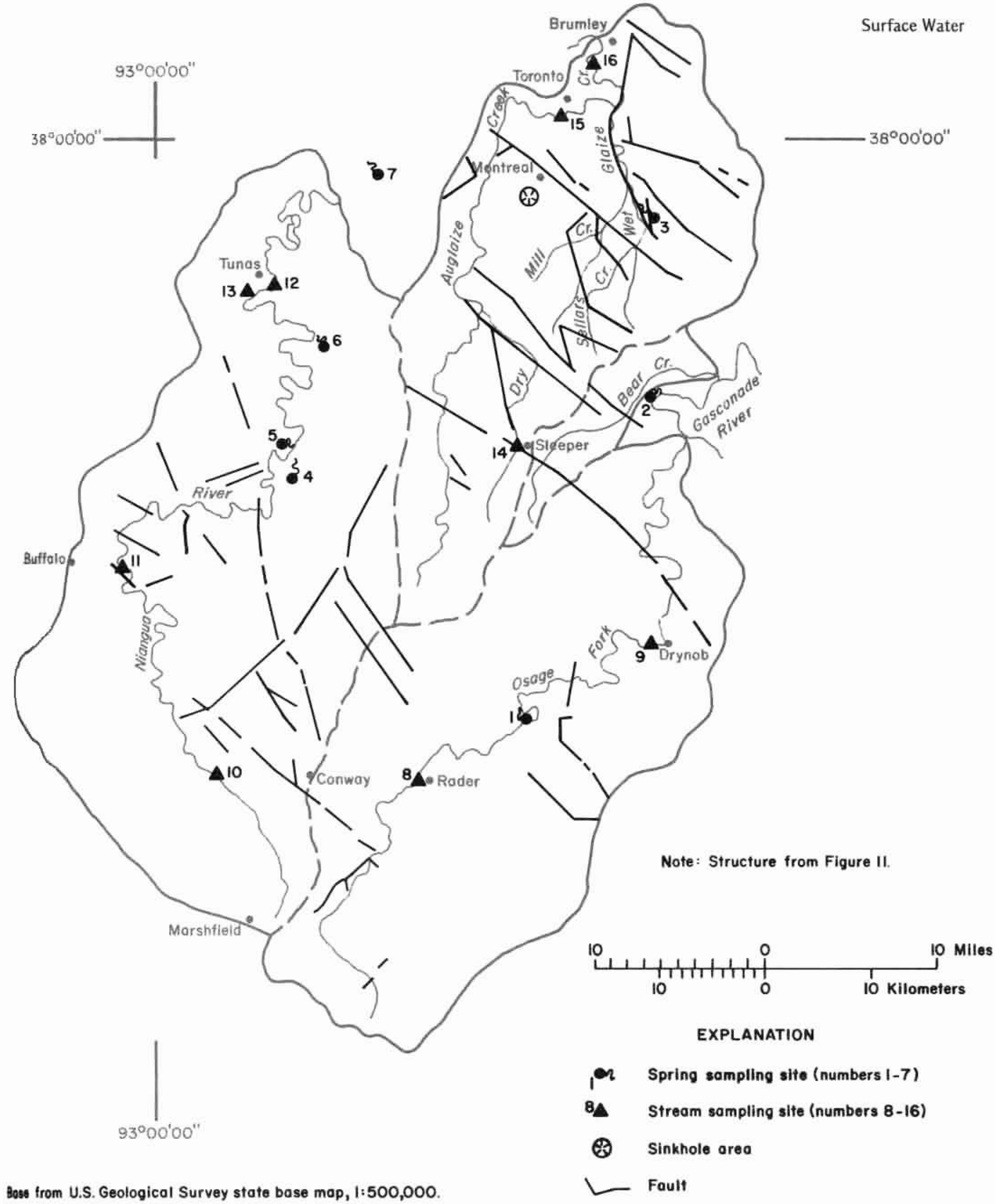


Figure 30. Water-quality sampling sites for streams and springs.

TABLE 7

Water-quality data for springs and streams (data in milligrams per liter except as indicated)

Map no. (fig. 30)	Station name and location	Date	Discharge (ft^3/s)	Conductance (μmho/cm at 25°C)	Temperature (°C)	pH (units)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Total nitrogen (N)	Total phosphorus (P)	Total calcium (Ca)	Total magnesium (Mg)	Ca/Mg (units)	Fecal coliform (col/100 ml)	Fecal streptococci (col/100 ml)
1	Little Spring	8-25-77	2.0	390	19	7.1	220	0	0.68	0.02	38	22	1.05	4	8
2	Cliff Spring	8-23-77	.81	480	14.5	7.3	290	0	1.6	.02	49	29	1.03	2	10
3	Blue Hole Spring	8-23-77	3.6	450	16	7.3	280	0	.62	.01	47	27	1.06	8	12
4	Bennett Spring	8-24-77	94	382	14	7.2	220	0	1.3	.02	37	22	1.02	18	16
5	Sand Spring	8-24-77	4.7	430	15	7.2	230	0	.76	.01	44	25	1.07	8	54
6	Sweet Blue Spring	8-24-77	21	430	14.5	7.0	260	0	.87	.12	44	25	1.07	14	6
7	Hahatonka Spring	8-23-77	57	390	14	7.4	230	0	1.1	.06	39	23	1.03	10	4
8	Osage Fork near Rader	8-25-77	13	377	25	7.8	230	0	.49	.06	38	23	1.00	220	220
9	Osage Fork near Drynob	8-25-77	59	320	26	7.9	190	0	.76	.06	33	19	1.05	120	30
10	Niangua River near Conway	8-25-77	.20	392	24.5	7.6	240	0	.34	.07	36	22	.99	65	280
11	Niangua River near Buffalo	8-25-77	28	390	23	7.9	240	0	.29	.04	40	24	1.01	55	140
12	Niangua River at Tunas	8-24-77	163	378	24	8.1	240	0	1.7	.04	38	23	1.00	5	20
13	Mill Creek at Tunas	8-24-77	2.7	470	21.5	8.0	300	0	.21	.0	50	28	1.08	230	310
14	Dry Auglaize Creek at Sleeper[1]	8-24-77	1.3	650	24	8.0	220	0	10	7.9	40	20	1.21	840	3,400
15	Dry Auglaize Creek at Toronto	8-23-77	.2	376	30.5	8.0	230	0	.05	.05	38	22	1.05	760	150
16	Wet Glaize Creek at Brumley	8-23-77	20	395	25.5	7.9	240	0	.27	.03	40	24	1.01	120	200

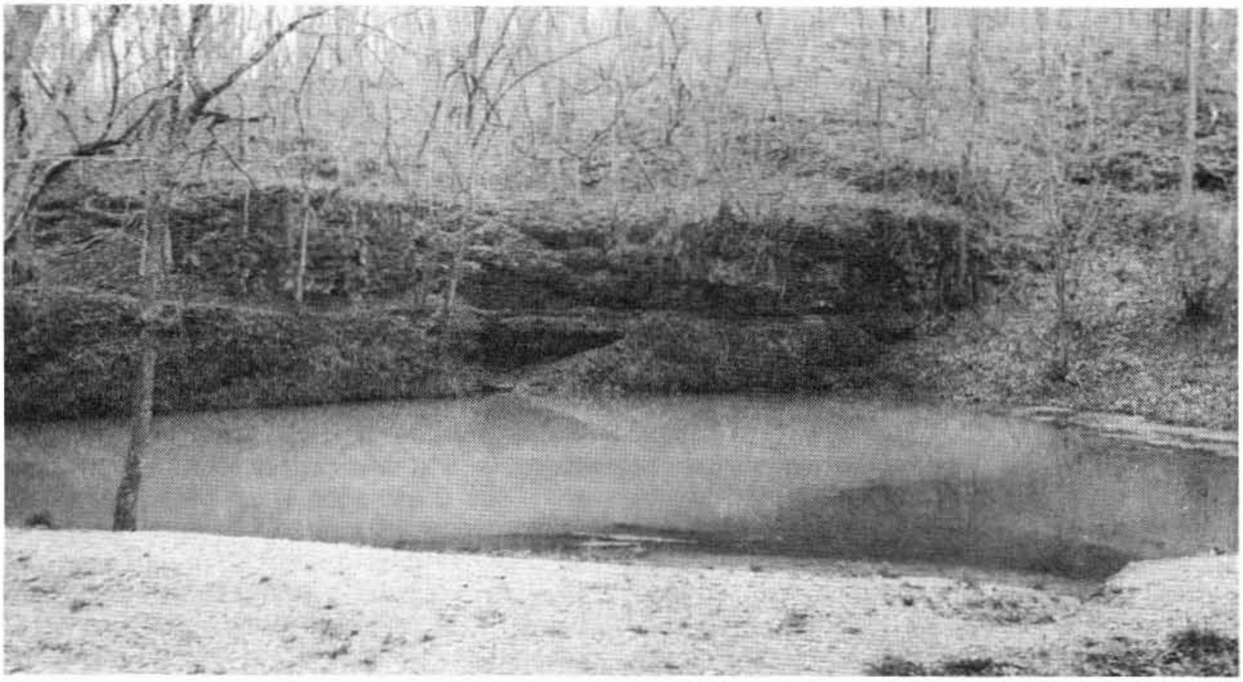
[1]Affected by outflow from sewage-treatment plant

jointing intersected the fault zone, such a cluster of sinkholes could develop and underground drainage could be directed to the site. At present (1978), the source of the pollution is unknown, but repetitive sampling and selection of additional sites on Dry Auglaize Creek should help identify it.

Bacterial counts in the Niangua and Osage Fork basins are highest in the upstream reaches and decline downstream. Because of the large contribution of groundwater from Bennett, Sweet Blue, and other springs in this reach, the decline is greatest on the Niangua River, between Buffalo (fig. 30, map no. 11) and Tunas (fig. 30, map no. 12). Similarly, the counts are reduced downstream on Osage Fork (fig. 30, nos. 8 and 9), but not to the degree that they are along the Niangua River.

Even scant water-quality data can provide clues to sources of pollution in the hydrologic system. For example, when springflow which normally contains a phosphorous content of 0.01 to 0.02 mgl (milligrams per liter) carries small, though abnormally high, amounts of phosphorus, it may be due to capture of waste-laden streamflow. On August 24, 1977, Sweet Blue Spring had an unusually high phosphorus content (0.12 mgl); on August 23, 1977, Hahatonka Spring, a smaller, though still unusually high, content (0.06 mgl) (plate 14). It should be noted that the norm for streams was about four times that for springs. A dye study (see *Groundwater Tracing*) showed that the flow lost from Dry Auglaize Creek, downstream from the Lebanon sewage-treatment plant, reappeared in the two springs; therefore, the high phosphorus content may indicate the presence of treatment-plant effluent. Since Hahatonka Spring has a greater flow than Sweet Blue Spring, dilution probably accounts for the smaller phosphorus content in Hahatonka Spring.

Plate 14A. Hahatonka Spring. Water issues from an opening at the base of the Eminence Dolomite bluff behind the gravel bar shown in the center of the photo. The water from this spring has slightly higher than normal phosphorous concentrations. Photograph by James E. Vandike.



B

C

Plate 14. 14B is a view of Sweet Blue Spring. Water from this spring had higher concentrations of phosphorous than Hahatonka Spring, due to less total dilution of the pollutant from increased discharge. The dye trace mentioned on page 99 showed dye emerging from these two springs. 14C is an aerial view of Sweet Blue Springs, showing its relation to the Niangua River (view toward southwest, with Niangua River on right and the spring just left of the bridge). Photographs by James E. Vandike.

GROUNDWATER-SURFACE-WATER RELATIONSHIPS

FACTORS AFFECTING RELATIONSHIPS

In Ozark basins, a number of related factors variably affect groundwater-surface-water relationships:

1. How saturated is the system? Antecedent conditions must be considered during any study of groundwater-surface-water relationships. Climatic extremes before an investigation may significantly alter hydrologic conditions and influence conclusions; this is a temporal factor.
2. How open is the system? Rock fracturing and subsequent solution can range from negligible to intense. The difference in altitude between the point of loss and the point of resurgence and their proximity to each other are factors that also influence the rate of solution and the resulting volume of storage.
3. How soluble are the rocks? Because of variable lithology, this is a difficult factor to evaluate. Brittleness and solubility determine the development of secondary permeability.
4. How large is the system? The area contributing flow to the point of loss may be large, contributing more to the loss area than it can take, except in dry weather. On the other hand, the contributing area may be relatively small compared to the loss area, so that all flows, except those resulting from intense storms, can be accommodated.
5. What part of the basin is involved? The geographical position of the loss area within a basin may also be significant, i.e., whether it is located near the headwaters, midway to the mouth, or near the mouth, a factor directly related to altitude and proximity of contributing and receiving areas (item 2 in this list). In general, the greatest depths to the water table have been observed in the upper and middle reaches of losing Ozark streams. In the project area, water levels are as much as 70 to 100 ft below flood plain along the upper parts of Steins and Dry Auglaize Creeks, and 10 to 20 ft below it along their lower reaches. In Ozark locations outside the project area, water levels may be as much as 250 ft below flood plain.

To study these factors, application of the methods described below was investigated. Following these descriptions, results of the studies of several of the basins in the project area are presented.

GROUNDWATER TRACING

The use of fluorescent dyes to compute travel times and observe dispersion patterns in surface streams is well-established, dependable, and useful (Wilson, 1968). For the current study, however, the relationship between surface water and groundwater was emphasized, especially in basins where surface flow is lost.

Groundwater tracing experiments using rhodamine WT dye (20-percent solution) were made in the Dry Auglaize Creek basin from May 1976 to April 1977. The results of these experiments are described in a paper by Skelton and Miller (1979); a brief summary of their findings is presented herein in order to evaluate the usefulness of groundwater tracing.

The location of the dye-injection site, dye-sampling sites, and the direction of underground dye movement are shown in figure 31 and plate 15. The dye was injected into Dry Auglaize Creek at site 1, where most streamflow during rainless periods consists of outflow from the Lebanon sewage-treatment plant (approximately 2 ft^3/s). Between sites 1 and 2, the flow disappears into the streambed, resurging in two large springs (sites 4 and 5, fig. 31) in the Niangua River basin.

The following is some of the information obtained from the dye study:

1. The upper Dry Auglaize Creek basin is one of the sources of recharge to Sweet Blue and Hahatonka Springs in the Niangua River basin.

Plate 15. Charcoal packets ("bugs") being collected and replaced at Ozark Fisheries spring, sec. 25, T. 37 N., R. 15 W., Camden County, as part of a dye trace of groundwater movement discussed on page 99 (Dye sampling site #8). Photograph by James E. Vandike.

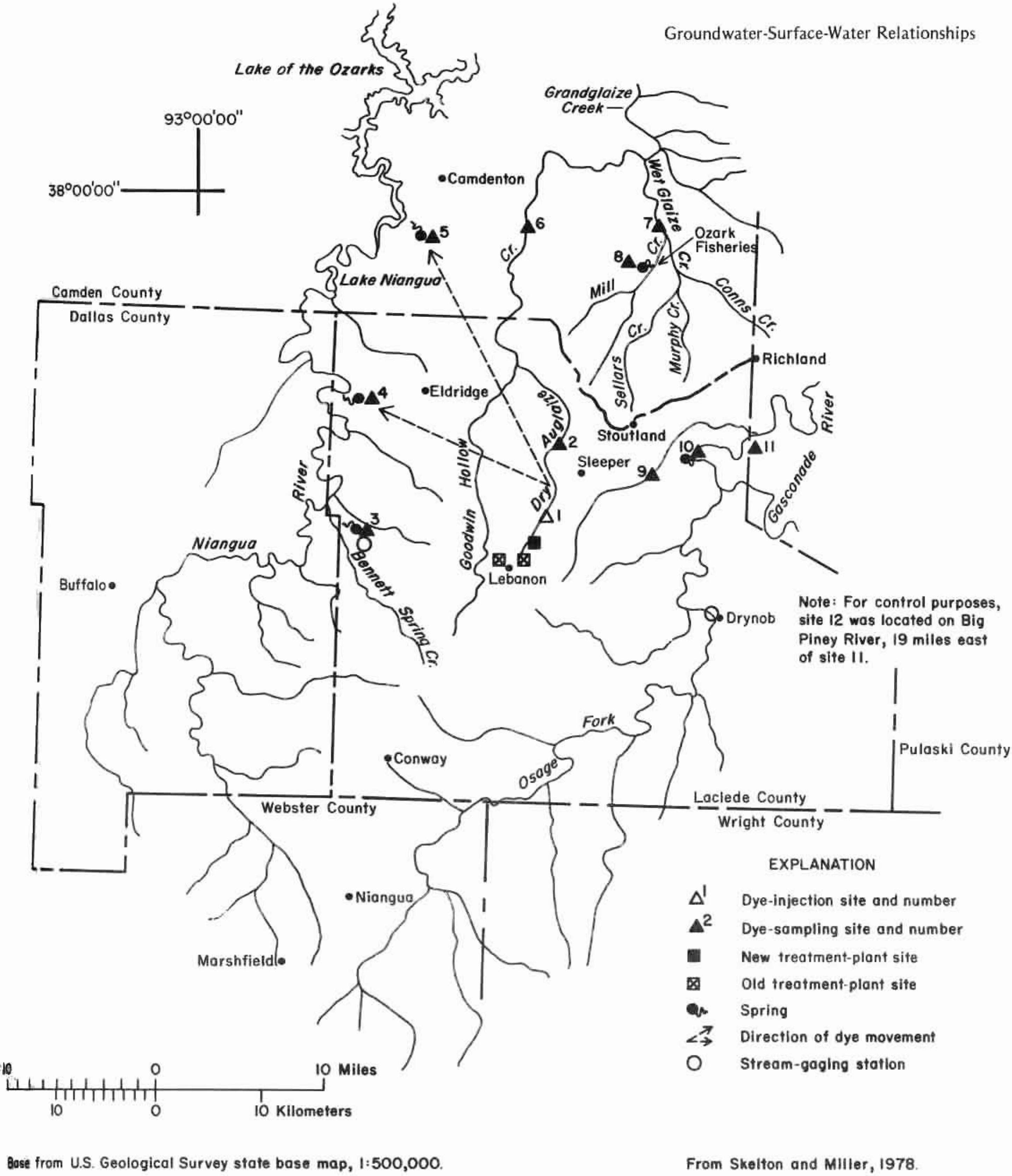


Figure 31. Location of dye-injection site, dye-sampling sites, and direction of dye movement.

2. The underground travel rate, based on straight-line distance from dye-injection point to resurgence points, was approximately 0.4 to 0.6 mi/d.
3. Geologic structure appears to control direction and rate of groundwater movement.
4. Studies of groundwater levels, streamflow patterns, and geology are insufficient to define resurgences of losing streams in carbonate rocks; they only indicate possible areas of resurgence.
5. Late fall and winter particularly favor successful groundwater tracing experiments using rhodamine WT dye, because background fluorescence is then lower and more stable.

VEGETATIVE INDICATORS OF HYDROLOGIC CHARACTERISTICS

Study of the relationships between hydrology and bottomland vegetation in the project area (Harvey and Skelton, 1978) has shown that identification of plants and plant assemblages is helpful in the study of carbonate hydrology. The following are some of the conclusions reached during the study:

1. Plant assemblages indicate gaining and losing conditions in Ozark stream valleys.
2. A change from one plant assemblage to another in a stream valley not recently altered or cleared, especially if the change is abrupt, suggests a marked change in depth to the saturated zone.
3. Plant assemblages indicative of differing hydrologic conditions can be used in any season (but not as readily in winter) to help evaluate low-flow characteristics of streams and groundwater-surface-water relationships.

Vegetation is most helpful in carbonate hydrology studies when used in conjunction with other information, such as groundwater levels, geology and structure, and seepage-run data. Vegetation, however, can be independently useful in defining areas of abrupt hydrologic changes.

ANALYSES OF GROUNDWATER LEVELS AND FLOW PATTERNS

The top of the saturated zone is a concave surface extending from the divide on either side of a basin to a stream and sloping downstream from headwaters to the mouth. Surface flow usually begins at places where this surface intersects tributary streams, at various distances upstream from their mouths.

Stream profiles, using groundwater levels, streamflow data, and topographic and geologic information are useful in studying the relationship of groundwater to surface water. The profiles in figure 32 illustrate the groundwater-surface-water relationships and complement the potentiometric map (fig. 13, in pocket).

In constructing profiles, water-level data were generally obtained from wells within a mile of the stream. In some cases where control could not be established near the stream, water levels were projected 1 or 2 mi from the uplands, resulting in a water-level profile probably somewhat higher in gaining reaches of the stream than the actual water level in the valley. In reaches of abnormally low water levels, almost all wells used were within a mile of the stream.

Osage Fork-Niangua River

The Osage Fork and Niangua River are perennial streams (type 1, fig. 29) for most of their lengths (fig. 32). Except for several short reaches, average groundwater levels stand above flood plain in each basin. Nowhere in the Osage Fork basin are groundwater levels more than 20 ft below flood plain, and in virtually the whole Niangua basin, water levels are above flood plain.

In the Osage Fork basin, water levels are at shallow depth below flood plain, in the reach from about mile 35 to mile 48, where Big Spring, the largest in the basin, is located. This suggests that there has been karst development, and that the wells supplying data may have been drilled into bedding planes or fractures filled with water having a lower head than that in the stream. During the drought of the mid-1950's, a 2-mi reach of Osage Fork upstream from Big Spring had no surface flow. Furthermore, as shown in figure 32, there is some decrease in surface flow in a 10-mi reach just downstream from Big Spring during years when base flows are normal. Thus, this reach of the Osage Fork, though perennial, does not conform to the pattern of continuous pickup along the rest of the main stem.

As noted by Harvey and Skelton (1978), the Osage Fork and Niangua River have similar vegetative patterns indicative of perennial flow conditions in Ozark streams. In the headwater areas, sandbar willow (*Salix interior*), Ward (Ward's) willow (*S. caroliniana*), stiff willow (*S. rigida*), sedges and rushes, watercress (*Nasturtium officianale*), and touch-me-nots (*Impatiens spp.*) gradually disappear and are replaced downstream by tall black willows (*S. nigra*), box elders, maples, sycamores, ashes, and elms.

Dry Auglaize Creek-Goodwin Hollow-Niangua River

Goodwin Hollow and Dry Auglaize Creek (type 3, fig. 29) are generally dry along most of their lengths and have the most extensive reaches of low groundwater levels in the area (fig. 32). Both streams flow only after intense rainstorms; they cease flowing within a few hours to a day or two. In dry weather, pools of water are more common along Dry Auglaize Creek than along Goodwin Hollow, indicating a more open underground drainage system in the Goodwin Hollow basin (plate 16).

Further proof of the greater infiltration capacity of Goodwin Hollow was obtained on March 31 and June 22, 1977. Following a rainstorm on March 28 and 29, in which 2 to 3 in. of rain fell in the area, landowners reported that Dry Auglaize Creek stopped flowing by March 30. However, a field reconnaissance for high-water marks showed that Goodwin Hollow had not flowed at all in the reach from mile 45 to the junction with Dry Auglaize Creek at mile 29, although there had been some flow in the creek upstream from mile 45. High-water marks indicated that rises of 1 to 2.5 ft occurred along Dry Auglaize throughout its length. In addition, all tributaries entering Dry Auglaize Creek from the east, between the mouth of Goodwin Hollow at mile 29 and mile 14, had trash lines and small flows or pools in their channels; those entering from the west, however, were dry, with no pools or trash lines. The underground drainage system of Goodwin Hollow and western tributaries of Dry Auglaize Creek will accept more storm runoff than Dry Auglaize Creek and its eastern tributaries.

More conclusive observations, following heavy rains of 3.5 to 6 in. on

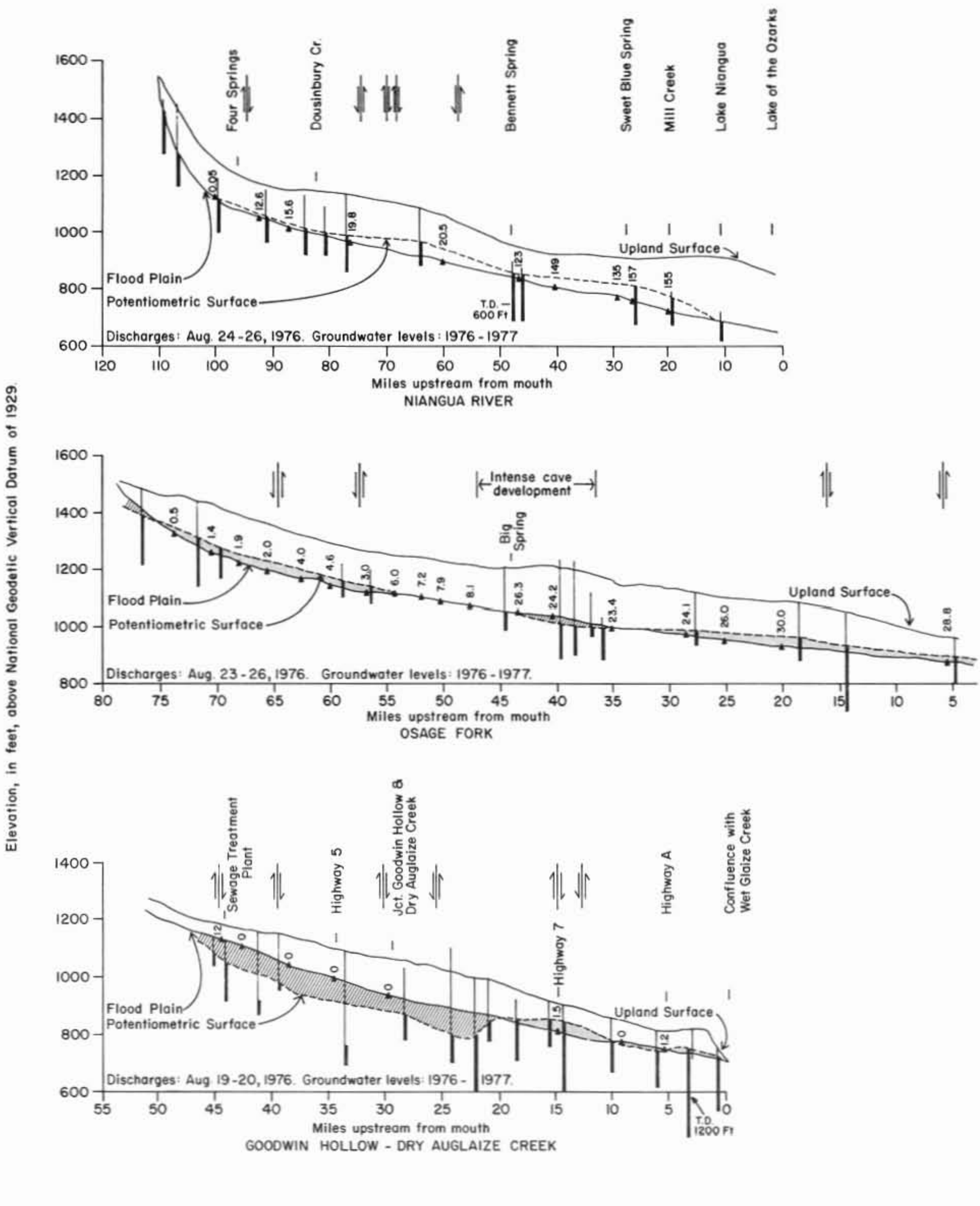


Figure 32. Profiles of streams showing relation between groundwater levels, streamflow, and faults.

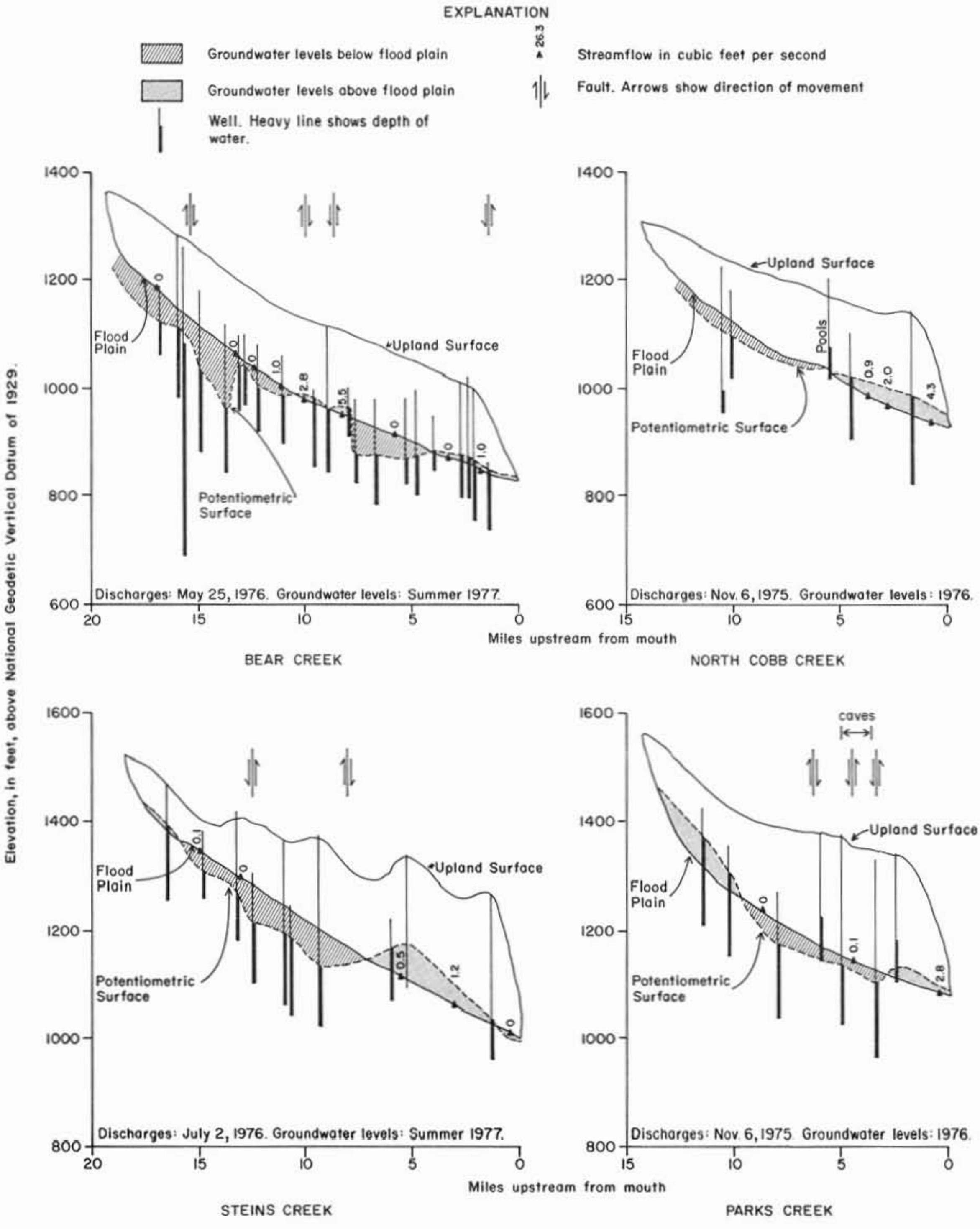


Figure 32 (continued)

A

B

C

Plate 16.
16A is a view of Dry Auglaize Creek, sec. 22, T. 37 N., R. 16 W., Camden County, showing dry creekbed and pools remaining from a recent rain. 16B shows poor sorting of gravels in the streambank along Dry Auglaize Creek at this site; angular chert fragments indicate little rounding by stream action (pencil near center of photo indicates scale). 16C is an aerial view of Goodwin Hollow, showing absence of pools. Photographs by James E. Vandike.

June 18 to 22, 1977, confirmed the large difference in infiltration capacity of Goodwin Hollow and Dry Auglaize Creek. Data from a number of municipal and private rain gages in the Lebanon area showed that the heavy rainfall was general in the two basins (fig. 33). Goodwin Hollow and Dry Auglaize Creek flowed along their entire lengths, and rises on the two streams were commensurate, ranging from 3 to 5 ft. Peak flows had passed by the time flow conditions were observed in the two streams on the morning of June 22. Measurements of flow and site locations are shown in figure 33.

The volume of storm runoff transmitted to underground storage was much greater in Goodwin Hollow than in Dry Auglaize Creek. Furthermore, the tributaries entering Dry Auglaize Creek, downstream from the mouth of Goodwin Hollow, had not flowed, and they revealed the same relationship they showed after the March rain. Both Goodwin Hollow and Dry Auglaize Creek are therefore losing streams. Goodwin Hollow, however, is more deficient in flow than Dry Auglaize, and the stream reaches and tributaries nearest to the Niangua River have the largest infiltration capacities.

An underground dye trace during this project (Skelton and Miller, 1979) has shown that the Niangua River is receiving flow from the upper reaches of Dry Auglaize Creek. Earlier dye studies reported by Vineyard and Feder (1974) and Dean and others (1969) revealed that Goodwin Hollow is also hydraulically connected to the Niangua basin; thus, interbasin stream piracy has been well established.

Harvey and Skelton (1978) observed that the vegetative patterns in Goodwin Hollow and Dry Auglaize Creek are typical of those in losing Ozark streams. Plants prominent in perennial stream basins occur only sporadically; these are found in the few reaches where groundwater levels are shallow and streamflow is perennial, or occasionally at the base of bluffs along dry streams. In such cases, however, the variety, abundance, and continuity of water-loving plants are lacking, and a strongly localized water-saturated condition seems to be indicated.

Bear Creek

As shown in figure 32, Bear Creek (type 4, fig. 29) has two dry and two wet reaches. The upper dry reach extends from the headwaters to about mile 10.5. Near this point, surface flow begins and extends downstream to about mile 7.5. From this point to mile 4.0 the stream is dry (plate 17). The downstream reach from mile 4.0 to the mouth has a shallow groundwater level, and there is usually some surface flow in the reach.

The lengths of the four reaches vary with the season and weather. In dry weather the wet reaches shorten considerably and the dry reaches lengthen, but the wet reaches always have at least a trickle of flow in them.

Groundwater levels in the two dry reaches stand below the level of the stream channel; in the gaining reaches they stand at or above it. There is the same relationship along Dry Auglaize Creek and Goodwin Hollow.

In the reaches of Bear Creek where there is no surface flow and water levels stand at some depth below flood plain, water that leaves the stream moves out of the basin to the Gasconade River. This was demonstrated when dye was injected at Bechtel's Ford in 1977 and recovered in Cliff Spring (plate 18 and fig. 21). Downstream from mile 7.5

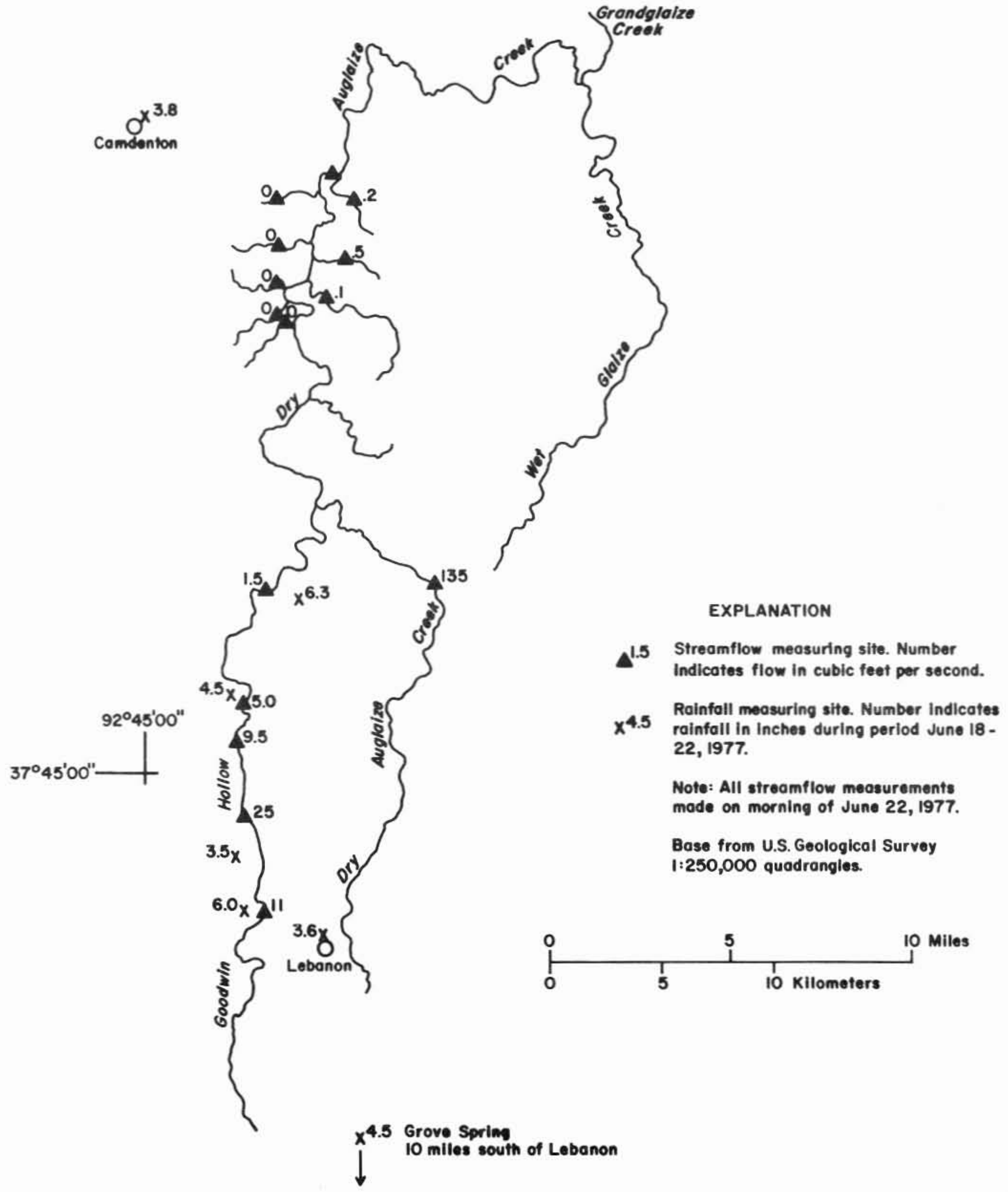
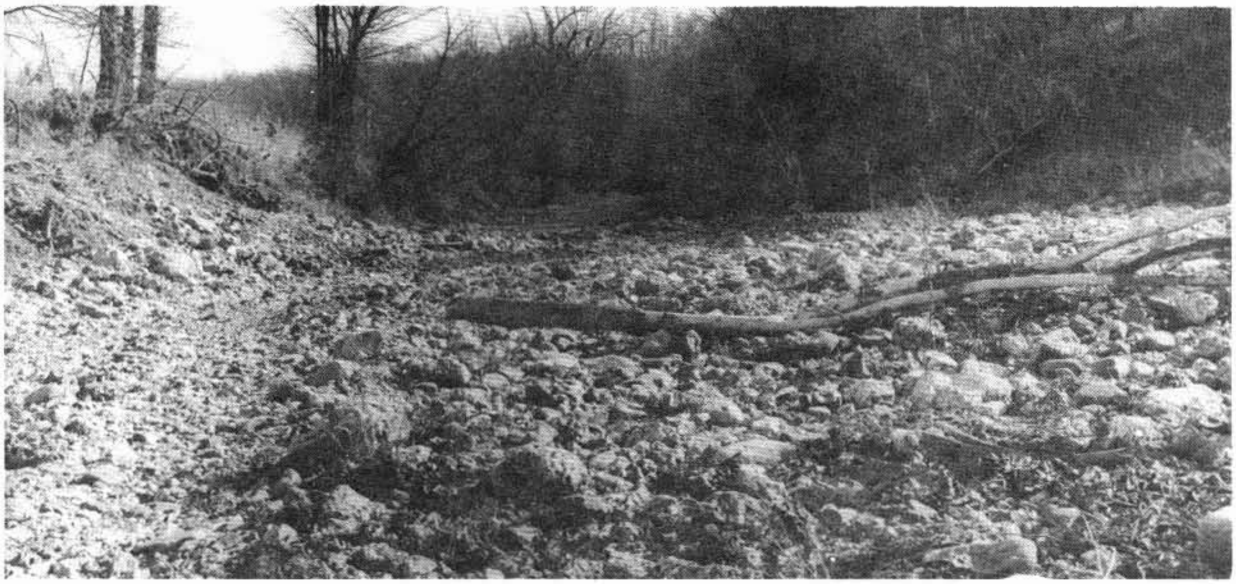


Figure 33. Streamflow patterns in Goodwin Hollow and Dry Auglaize Creek following heavy rainfall.

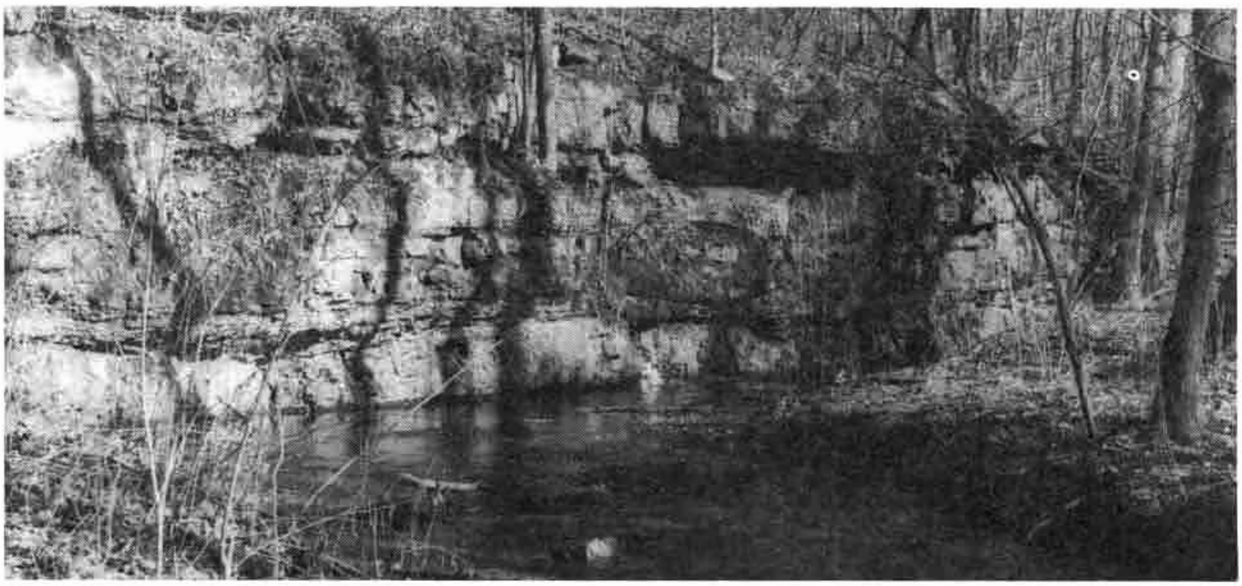


A

B

Plate 17.
17A is a downstream view along a dry reach of Bear Creek, sec. 5, T. 35 N., R. 14 W., Laclede County, downstream from Bectels Ford. 17B shows sorting (or lack thereof) of gravels in streambank just left of view in 17A. Photographs by James E. Vandike.

A



B

Plate 18. 18A is a view of Bectels Ford on Bear Creek, sec. 7, T. 35 N., R. 14 W., Laclede County. Dye placed in the stream at this point was lost to subsurface flow a short distance downstream and emerged at Cliff Spring, sec. 9, T. 35 N., R. 14 W., Laclede County. Flow from the spring shown in 18B depends almost entirely on flow in Bear Creek, at Bectels Ford. Photographs by James E. Vandike.

(fig. 32), there is a steep gradient in the groundwater level. In effect, there exists a large depression in the water-level profile, extending to the gaining reach that begins about 4 mi upstream from the mouth.

Willows and other water-loving vegetation are scattered along the dry reaches of Bear Creek. They do not become prominent until perennial groundwater discharge and shallow water levels occur. The gaining reaches of the

stream have a diversified suite of abundant water-loving plants; the losing reaches, on the other hand, have less variety and abundance.

North Cobb Creek

The longitudinal profile of the altitudes of the upland, flood plain, and average groundwater level in North Cobb Creek basin (fig. 32) shows that about 6 mi upstream from the mouth, groundwater levels begin to stand above the stream profile. At this point the stream (type 4) becomes perennial as shown by the flow measurements (fig. 32). Water levels always stand close to the ground surface even though evaporation depletes the groundwater inflow, so that in late summer the flow may be reduced to a trickle between pools.

Upstream from the point where perennial flow begins, there is a marked change in stream gradient, and the stream profile and groundwater profile diverge toward the divide, with an increase in the available volume of storage between the upland surfaces and the zone of saturation. In a large part of the upstream section of the basin, the Roubidoux Formation underlies the surface (fig. 4, in pocket). Here the Jefferson City Dolomite has been eroded away, sinkholes are common, and the rock and soil sections of the entire Roubidoux outcrop area are conducive to infiltration and storage of precipitation.

Within the reach where the stream gradient steepens downstream, water-loving plants become more prominent. Between this point and the mouth of the stream, no stream losses occur as the flow gradually increases to the mouth. Thus, groundwater levels, streamflow, topography, and vegetation combine to define the low-flow characteristics of the stream. Vegetation upstream usually does not include water-loving types, but small colonies of willows and sedges may exist where the stream runs along the base of bluffs.

Steins Creek-Parks Creek

Steins Creek, an interrupted stream (type 3, fig. 29) tributary to Osage Fork, is an example of a stream whose lack of flow is probably related to faulting and solution along a fault system. Two parallel faults forming a horst cross the basin midway between the headwaters and the mouth, where the Gasconade Dolomite is at the surface (figs. 4 (in pocket) and 32). There is no flow in Steins Creek (except for a trickle in the headwaters) until it crosses the horst; from there it is perennial until it reaches a point near its confluence with Osage Fork.

Parks Creek (type 3), in the adjacent basin to the west, is somewhat smaller than Steins Creek, but exhibits similar geology. The base flow of Parks Creek, however, is larger than that of Steins Creek in the downstream reach (fig. 32), and it is possible that flow from the upstream reach of the latter is being diverted to the downstream reach of Parks Creek, along or in the fault block shown in figure 34, a possibility suggested by decreasing groundwater levels to the northwest.

An alternative to northwest subsurface discharge from Steins Creek is northeast discharge to the Gasconade River. Groundwater levels also decline toward the Gasconade basin. Groundwater movement in that direction is possible; in fact, contours on the potentiometric map (fig. 13, in pocket) suggest discharge in that direction.

A comparison of elevations along the two streams also helps to show why

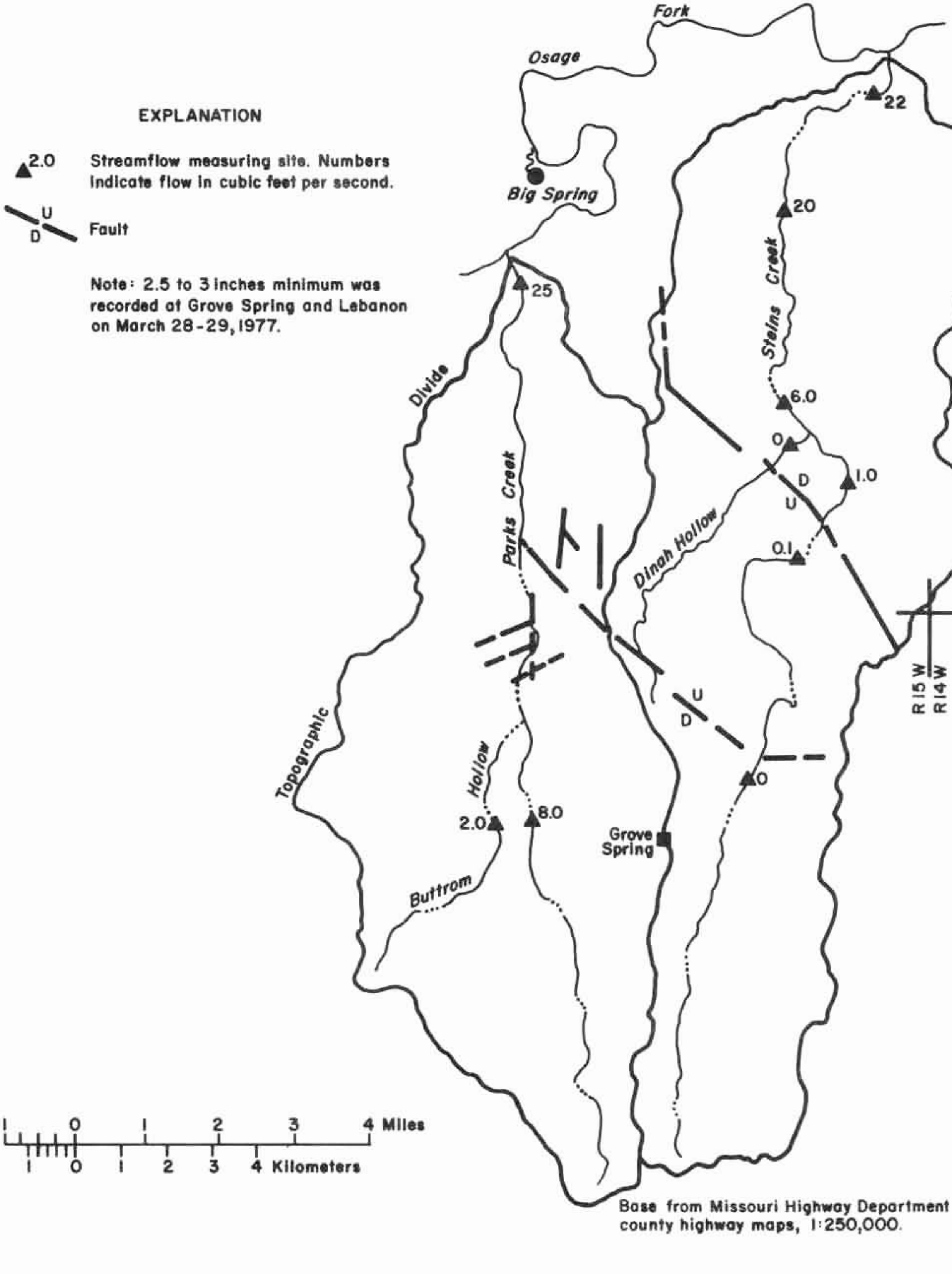


Figure 34. Streamflow in Steins and Parks Creek basins, March 30, 1977.

hydrologic conditions in the two basins may differ. The 1100-ft elevations of both streams are at about the same latitude, and each stream reaches the divide at nearly the same elevation (1540-1560 ft). Downstream from the divide, at the latitude where the elevation of Steins Creek is 1300 ft, that of Parks Creek is about 1230 ft.

The relationship between these adjacent basins was further studied following 2.5- to 3-in. rains on March 28-29, 1977 (fig. 34). Note that the flow from the smaller, Parks Creek basin was still somewhat larger than that of Steins Creek in the lower reaches and that the flow in Steins Creek, even under saturated conditions, was apparently influenced by the structural features shown in figure 34. Even under differing hydrologic conditions, less flow is contributed from the upstream part of Steins Creek basin than from the smaller, Parks Creek Basin.

The distribution of water-loving plants and their relation to streamflow and groundwater levels in the Steins Creek basin have been described by Harvey and Skelton (1978). In Parks Creek basin, vegetation patterns similar to those along Steins Creek were observed. Plant diversity is limited by the lack of adequate water in the upper reach of Parks Creek, where flow is intermittent. Near the mouth, where flow is perennial and water levels are shallow, plants are more diversified.

Similar relationships between groundwater levels, streamflows, and vegetation can be anticipated for tributaries not described here. The observation of dry-weather flow in the middle reach of a valley does not preclude a dry streambed between that point and the mouth; nor does the observation of a dry streambed in mid-valley preclude a perennial reach upstream. Observation of streamflow conditions can be used to predict variations in groundwater levels in a basin; conversely, observation of groundwater levels can be used to predict streamflow characteristics. Vegetation is a key to both. In addition, observation of anomalies in these three elements may suggest that more detailed geologic mapping is warranted.

Using all available hydrologic data, the authors classified areas of recharge and discharge along streams in the three-basin region, as shown in figure 35. The illustration is a generalized presentation intended to show areal distribution of recharge and discharge; in effect, it summarizes many of the conclusions presented in the report.

Drainage-Density Analysis

Using a method described by Trainer (1969), drainage densities were computed for a number of streams in the project area and for several Ozark streams in other parts of southern Missouri to determine the usefulness of the method as an indicator of low-flow characteristics. Trainer's studies were useful in sandstone, shale, and metamorphic rock terranes in the investigation of groundwater discharge and its relation to the development of the drainage network. Figure 36 is a plot of drainage-density values for Ozark streams, versus the 7-day median low flow (7-day Q_2). Because of excessive scatter, the data plot in figure 36 did not prove conclusive.

Because of development of underground drainage, the drainage-density-low-flow relationship is not clear in karst terranes such as the Ozarks. Originally a drainage network was

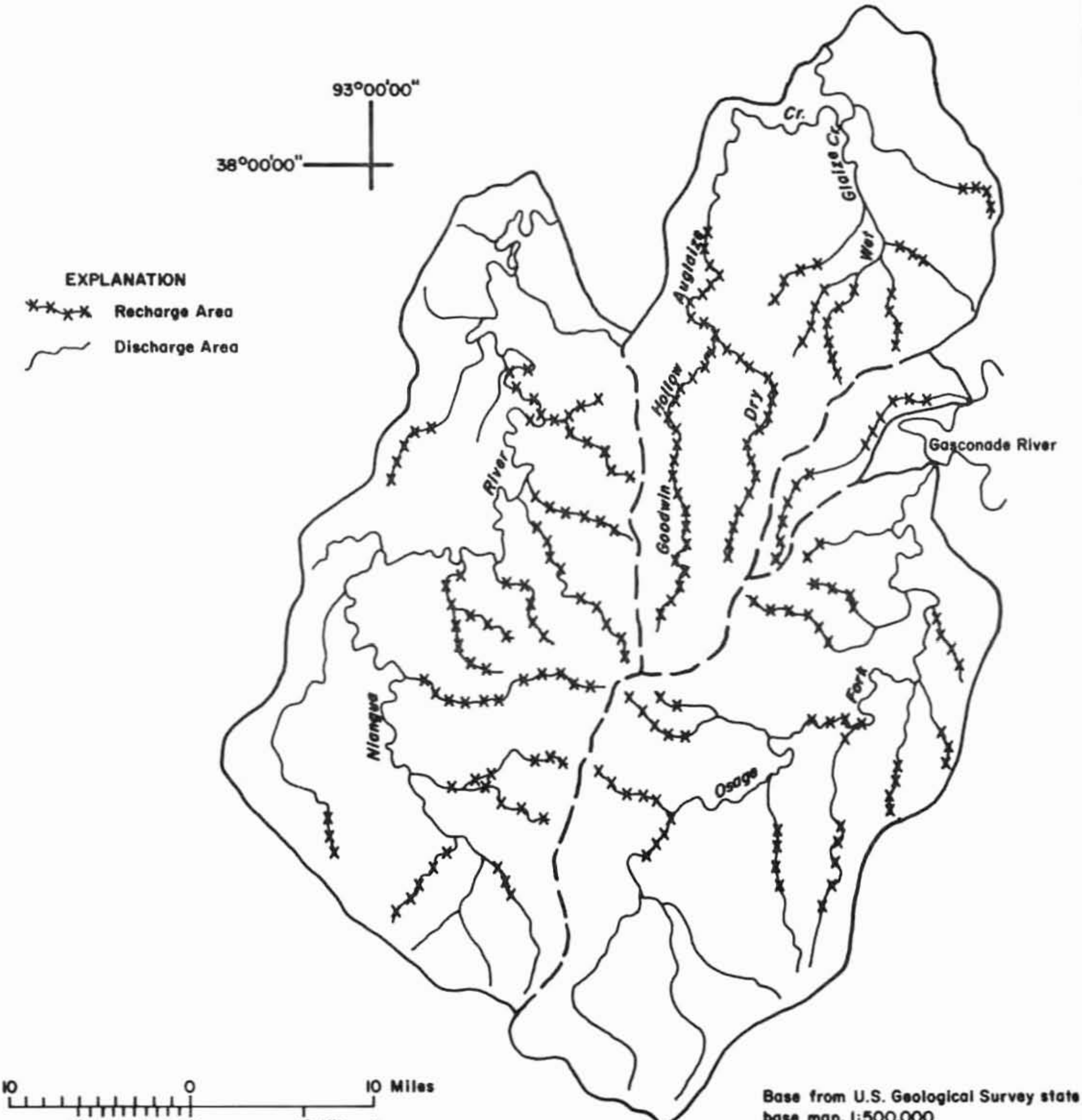


Figure 35. Recharge and discharge along streams, based on hydrologic data.

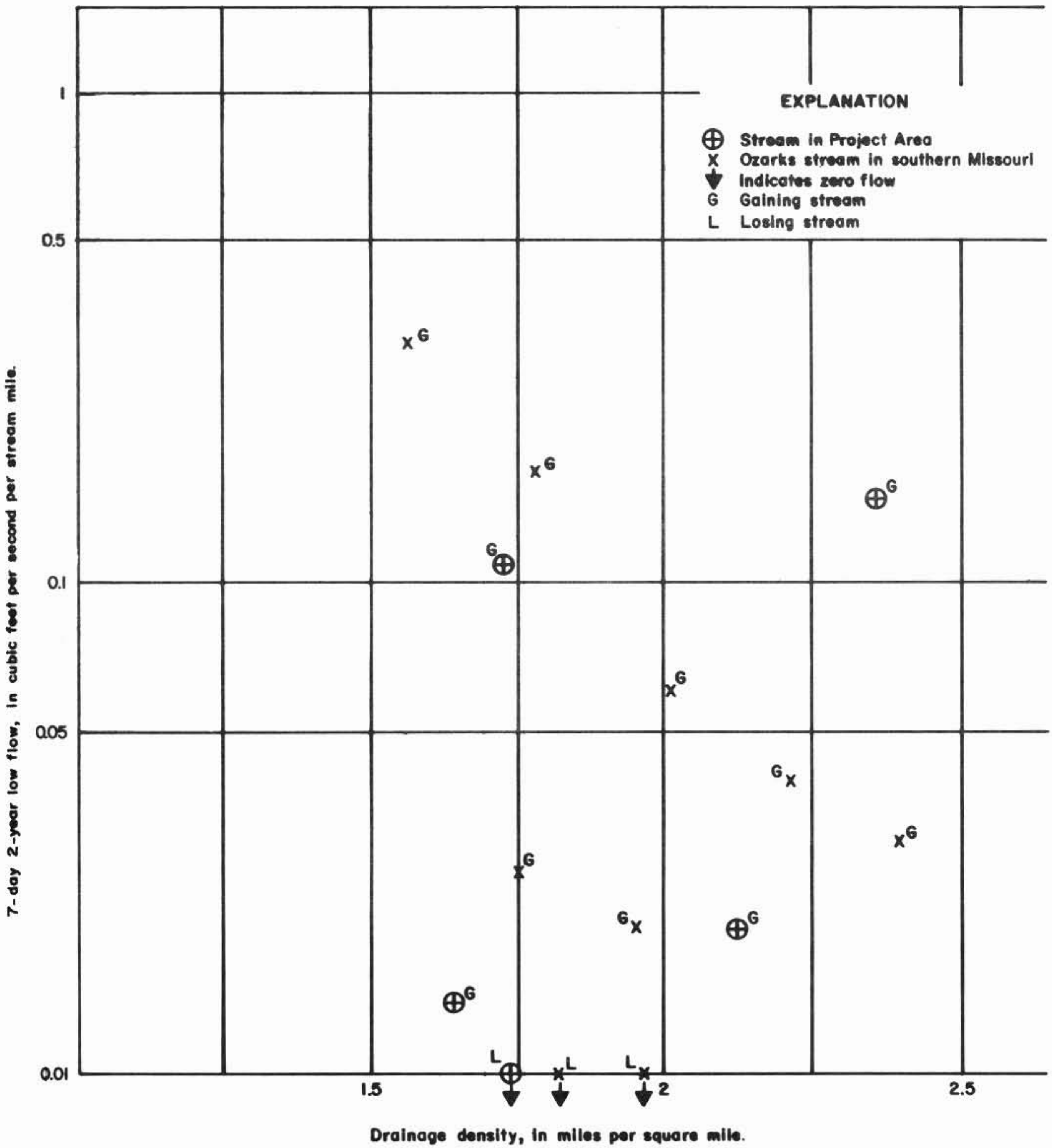


Figure 36. The relation of 7-day Q_2 to drainage density.

established on a surface with little or no solution development, underlain by dolomite. As dissolution of the dolomite advanced, the surface-drainage network continued to exist, but groundwater discharge to the stream declined or remained at a high level, depending on the amount of diversion taking place between basins. As a result, two stream networks with nearly the same density can coexist in the same area, with little or no correlation with groundwater discharge.

The authors have concluded that there may be a range of drainage densities that typify losing or deficient streams, and that there also may be a family of drainage-density curves characteristic of perennial streams. However, because of the time required to make a comprehensive drainage-density study of Ozark basins, and the availability of other methods, considered more reliable, in defining gaining and losing streams, the authors have concluded that drainage density may not be useful as a predictive hydrologic tool in carbonate karst terrane.

REMOTE SENSING AND THERMAL DATA

Satellite imagery may be useful in defining gross hydrologic differences between large basins like the Dry Auglaize Creek and Niangua River basins. The terrain in the area comprising Goodwin Hollow, upper Dry Auglaize Creek, and the adjacent part of the Niangua River basin has a characteristic drab appearance on color-enhanced imagery, distinguishing it from other areas where groundwater levels are shallow. The drab appearance of the area is believed to be caused by moisture-stressed vegetation; however, these gross hydrologic differences were already known before the project was begun. After examining available imagery, the authors decided an evaluation by other methods would yield specific data more significant to the project.

In a recent study in Missouri, low-altitude thermal imagery was shown to be useful in distinguishing between recharge and discharge areas along stream valleys on the Salem Plateau (Harvey and others, 1977). Based on the results of that study, the authors concluded that low-altitude thermal imagery of losing streams like Dry Auglaize Creek and Goodwin Hollow, Conns Creek in the Wet Glaize Creek basin, Jones Creek in the Niangua basin, and Steins Creek in the Osage Fork basin should exhibit thermal characteristics similar to those of Logan Creek, a losing stream in the Black River basin (fig. 1).

Low-altitude thermal imagery and computer evaluation of the data are very expensive; in addition, obtaining significant data requires precise timing (time-of-day and season) and good flying weather. The authors have concluded that it would be necessary to have locally available equipment, which could be used within a few hours notice, to collect low-altitude thermal data effectively.

Because thermal data are recognized as potentially useful in distinguishing between gaining and losing streams, it was decided to use thermocouples to obtain shallow-depth temperature data. A previous investigator (Cartwright, 1968), discovered that soil temperatures above water-filled sand and gravel lenses in glacial till were generally higher in winter and lower in summer than soil temperatures elsewhere in the till. He also found that diurnal fluctuations of air temperature did not significantly affect soil temperatures at depths exceeding 1.5 ft (Cartwright, 1968).

TABLE 8

Soil temperature differences in flood plain soils of gaining and losing streams at a depth of 2.5 feet
(Temperatures in degrees Celsius; all dates 1977)

Stream	Winter							Spring											Summer	
	1/19	1/24	3/1	3/7	3/14	3/17	3/18	3/24	3/30	3/31	4/15	5/3	5/12	5/24	5/25	6/1	6/7	6/8	8/11	8/15
Bear Creek[1]	+4.7	--	--	+3.6	--	+3.8	+2.6	--	+2.0	--	--	+0.9	--	+0.1	--	--	-0.3	--	+0.8	--
Benton Creek[2]	--	+1.6	+2.5	--	+1.4	--	--	+2.0	--	--	+2.3	--	-1.4	--	--	+1.0	--	--	--	-0.5
Conns Creek[3]	--	--	--	--	--	+1.8	+1.8	--	--	+5.1	--	--	--	--	+8.6	--	--	+8.7	+8.9	--

[1]Bear Creek (gaining reach minus losing reach).
[2]Benton Creek (gaining) minus Norman Creek (losing).
[3]Conns Creek (gaining) minus Deberry Creek (losing).

Thermocouples were installed 2.5 ft beneath ground level at three locations in gaining and losing reaches of Bear, Dry Auglaize, Conns, and Deberry Creeks in the Lebanon area. A control set of thermocouples was installed on Benton (gaining) and Norman (losing) Creeks in Phelps County, near Rolla (fig. 1), where more frequent measurements could be made.

Table 8 lists observed soil temperature differences. Winter temperatures (January 19 to March 18) for Benton Creek and the wet reach of Bear Creek averaged 2.9°C warmer than those of Norman Creek and the dry reach of Bear Creek. In spring (March 24 and June 8) the average temperature of the wet reaches was 0.8°C higher than that of the dry reach. In August the average of two values for the wet reaches was still 0.15°C higher than that of the dry reach. In winter, when vegetation was dormant, temperatures in the wet reaches were always higher than those in the dry reach, a finding consistent with results obtained during low-altitude flights (Harvey and others, 1977).

Noting the vegetative cover at the time of the measurements, it became apparent that cover greatly influenced the temperature levels in the summer. As Cartwright (1968) observed, "temperature variations caused by changes in vegetation and shade were the two most difficult problems faced in the field." By June 7, 1977, the pasture and hayfield at the gaining site on Bear Creek had been cut, but the cover was still fairly thick at the losing site, where a good cover of weeds and grass remained. The temperature was slightly lower at the gaining than at the losing site. On August 11, 1977, the losing site was a little cooler than the gaining site. Cover at the losing site was a fairly tall, thick stand of weeds; that at the gaining site, scattered straw and a few clumps of weeds.

On June 1, a similar temperature reversal was noted in comparing Benton and Norman Creeks and the difference was more pronounced. Just before June 1, the hay had been cut at Benton Creek, but that at Norman Creek had not been cut.

A thermocouple in a losing reach of Deberry Creek became progressively more shaded as the year advanced. Although the water table was deeper on Deberry Creek than in the gaining reach of Conns Creek, the Conns Creek site remained warmer during the summer than Deberry Creek, probably due largely to shade and thick cover at the Deberry Creek site. Thin pasture grass covered the Conns Creek site through the summer.

From these observations it is concluded that changes in vegetative cover during the summer months measurably affect ground temperatures, even at 2.5-ft depths, thus complicating interpretations.

In summary, soil temperature measurements obtained in the winter should be more conclusive than those obtained in the summer, because shading and the insulating effect of vegetation are not problems. The temperature profile in the ground is radically altered by hay cutting, heavy grazing, or removal of plant cover. As a tool to support the findings from other lines of investigation, shallow-depth soil-temperature measurements are useful, but the method is neither as practical nor as specific as other methods, such as surface-flow and groundwater-level measurements, in identifying infiltration characteristics.

ENGINEERING GEOLOGY OF CONNS CREEK DRAINAGE SYSTEM

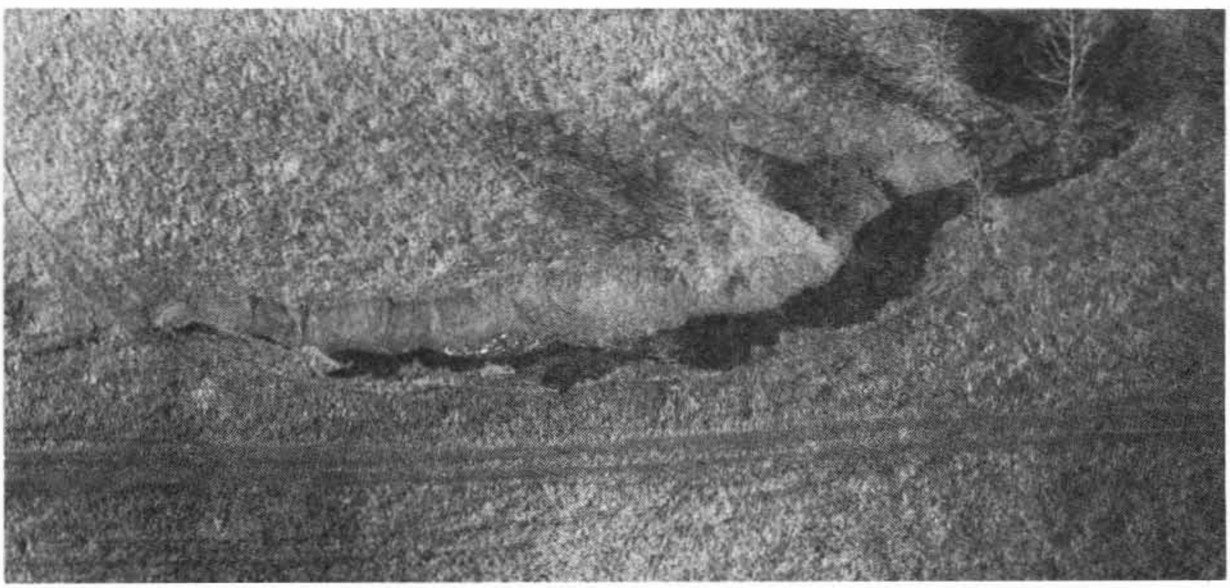
Thomas J. Dean

An engineering geology study of Conns Creek, in the Grandglaize Creek basin, showed that such a study can be very useful in relating site evaluation for waste disposal, water impoundment, or foundation investigation on a small tributary or stream reach to the investigation of an entire basin. Test drilling showed conclusively that the alluvial fill is incapable of transmitting large volumes of water after a rain and that conduits formed in bedrock by solution are required to carry such flows.

Conns Creek represents about 7 percent of the Grandglaize Creek drainage area (plate 19). Its geologic setting is typical of surface and subsurface conditions in much of the Ozarks; therefore, the basin was chosen as one that could serve as a prototype for future engineering geology work in the Ozarks.

Conns Creek, with a drainage area of about 25 mi^2, rises in the city of Richland and flows approximately 8 mi to its confluence with Wet Glaize Creek (fig. 37). Deberry Creek, a principal tributary, drains approximately 9 mi^2.

A



B

Plate 19. 19A is an aerial view westward of Conns Creek, sec. 22, T. 37 N., R. 13 W., Camden County. Note the very broad, well-defined valley, a type present even in severely losing Ozark stream reaches, such as the reach of Conns Creek pictured in 19B. This aerial view of Conns Creek shows the stream immediately downstream from its junction with Deberry Creek. Photographs by James E. Vandike.

The main stem of Conns Creek follows the local northwesterly bedrock dip of about 19 ft/mi. In ascending order, bedrock formations at the surface are the Roubidoux Formation, the Jefferson City Dolomite, and the Cotter Dolomite.

Faulting may have affected the geomorphic development of the Conns Creek drainage system, as indicated by the parallelism between Conns Creek, subsurface flow, and a major northwest-trending fault (fig. 37) that nearly

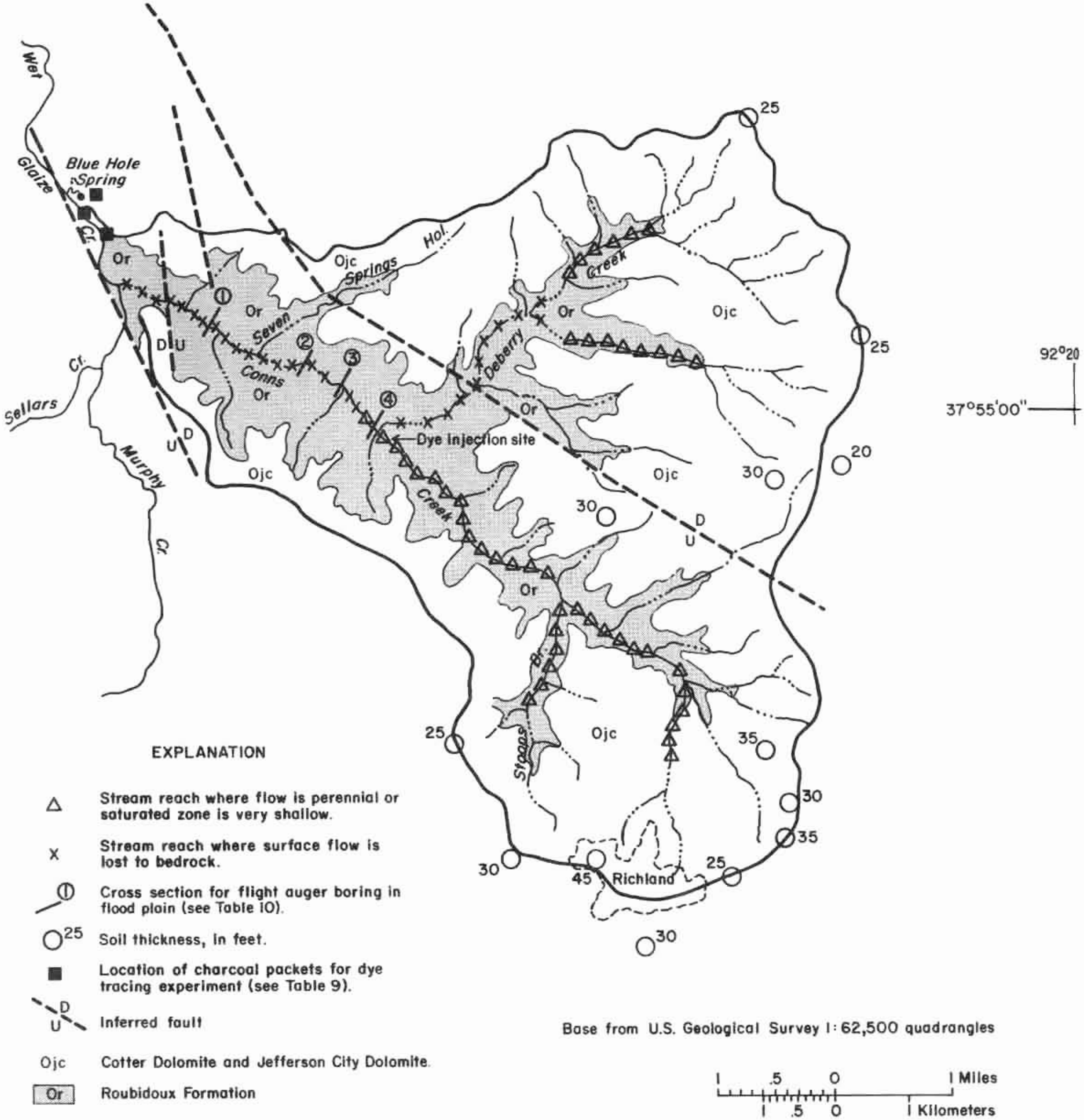


Figure 37. Geologic and hydrologic data and data-collection sites for engineering geology study in Conns Creek basin.

bisects the basin and appears to be continuous, although it is difficult to trace in the thick residuum at the eastern edge. Other mapped faults cross the lower part of the basin, and mapping suggests the existence of additional, though minor, faults. Blue Hole Spring, approximately three-fourths of a mile downstream from the junction of Conns Creek and Wet Glaize Creek, lies adjacent to a northwest-trending fault.

In ascending order, the Roubidoux Formation consists of massive cherty reefs, fine- to medium-grained cherty dolomite, and massive coarse-grained sandstone. The reefs are exposed in the lower reach of Deberry Creek; the cherty dolomite, along Conns Creek, where it forms low bluffs; and the massive sandstone, on both sides of the valley, near the mouth of Conns Creek.

Where the Roubidoux is exposed, rugged topography results from dissolution and varying lithology, and from joints, which create a very high permeability, attested to by the abundance of sinkholes and slump features, in the shallow subsurface. Lateral movement of water along fractures in drainage divides is as common as leakage from impoundments. The Roubidoux outcrop is a recharge area in many places.

The residual soils developed on the Roubidoux Formation are 10 to 40 ft thick and permeable, particularly where the bedrock contains much chert, and massive sandstone beds. The total soil column comprises alternating zones of gravelly sandy clay and broken chert layers. Horizontal permeability is extremely high, particularly in the cherty gravel zones.

The residual soils of the Roubidoux are classified in the Unified Soil Classification System as GC (U.S. Army Corps of Engineers, 1960). The Atterburg classification of the fine fraction (less than 0.03 in.) is ML to CL, with a clay content of between [illegible] and 25 percent. Vertical permeability of undisturbed samples of the stony clay portion of the soil column is estimated to be approximately 2.8 x 10^{-2} to 2.8 x 10^{-3} ft/d.

The soil normally has a low pH, ranging from 5 to 6, a result of prolonged leaching. Soil formation in zones of intense faulting and fracturing is promoted by percolation of water through the acid soil. The highly pinnacled soil-bedrock contact influences the direction of shallow groundwater movement.

The Jefferson City Dolomite is principally a thin-bedded, fine- to medium-grained, clayey dolomite with thin, discontinuous beds of chert. The overlying Cotter Dolomite normally contains little chert elsewhere in the project area, but in the Conns Creek basin its residuum is very cherty. The Jefferson City is exposed in the uplands in most of the basin, whereas the Cotter is recognized only in study of residual materials in drill cuttings from wells in the upper part of the basin.

Residual soils developed on the Jefferson City and Cotter Dolomites range from 20 to 45 ft thick (fig. 37). The soils of the two formations are similar, except that the Cotter soil contains much more chert than the Jefferson City soil, approaching 50 percent in some localities. Both have a Unified Classification of gravelly clay, CL to CH; permeabilities range from 2.8 x 10^{-2} to 2.8 x 10^{-4} ft/d. Their fabric is uniform, compared to residual soils on the Roubidoux Formation.

Permeabilities of the residuum on the Roubidoux Formation and Jefferson City

and Cotter Dolomites have a similar range. Because of the heterogeneity of the soils derived from the Roubidoux, compared to the more homogeneous soils derived from the Jefferson City and Cotter Dolomites, values based on core determinations do not completely represent the permeability of the Roubidoux. The cores represent a very small sample of the soil characteristics.

Soils on the Jefferson City and Cotter Dolomites do not readily allow rapid recharge of groundwater. Surface runoff and horizontal, rather than vertical, movement of water in the soil is prevalent, especially where a fragipan exists. Where excessive fracturing and solutioning of the underlying Roubidoux Formation have caused slumping and fracturing of the Jefferson City Dolomite, infiltration is promoted. Where residual soils are thin, the bedrock sheds rather than absorbs water. The low infiltration capacity of the Jefferson City and Cotter contrasts with the high infiltration capacity of the Roubidoux. Stream-channel development is well defined in areas underlain by the Jefferson City and Cotter Dolomites; the streams are gaining rather than losing. Farm ponds and lakes constructed in the residual soils of the Jefferson City and Cotter pond water readily.

Figure 37 shows the gaining and losing reaches of Conns Creek (type 3, fig. 29), as defined by streamflow measurements and water levels in wells. The upper reach of Conns Creek is a gaining stream to a point near its junction with Deberry Creek. Downstream from this point, surface

TABLE 9

Dye tracing of subsurface flow in Conns Creek Basin

[Two pounds of fluorescent yellow injected on March 23, 1977, at 1530 hours in Conns Creek, 100 yards upstream from junction with Deberry Creek. Dye extracted from charcoal packets by elutriating with 5 percent potassium hydroxide in ethyl alcohol and detected by observing solution with high-intensity lamp]

Site location (fig. 37)	Date of observation	Visual results
Wet Glaize Creek at low-water crossing	3-14-77	Negative
	3-25-77	"
	3-30-77	"
	4-5-77	Packets lost in flood
	4-7-77	"
Wet Glaize Creek upstream from Blue Hole Spring	3-14-77	Negative
	3-25-77	"
	3-30-77	"
	4-5-77	"
	4-7-77	"
Blue Hole Spring	3-14-77	Negative
	3-25-77	"
	3-30-77	Weak positive
	4-5-77	Very positive
	4-7-77	"

flow is lost to bedrock (plate 19B). Similarly, Deberry Creek gains in its upper reaches, and loses in the lower.

In March 1977, fluorescent dye placed in Conns Creek where water loss occurs at its confluence with Deberry Creek was recovered at Blue Hole Spring, on Wet Glaize Creek (table 9 and fig. 37), but did not appear in Wet Glaize Creek farther upstream.

In June 1977, after the dye trace, exploration holes were drilled on Conns Creek flood plain to determine if water was carried in the alluvial fill. The holes were drilled along sections perpendicular to the creek, in both losing and gaining reaches (table 10). Cross sections 1, 2, and 3 are located in the losing reach of the stream and show dry alluvium to bedrock (fig. 37). A marked difference in depth to bedrock between sections 1 and 2 correlates with faulting mapped near the mouth of the creek, suggesting deeper weathering at section 1. Cross section 4 is in the gaining reach and confirms the existence of water in the basal 3 to 4 ft of the alluvial material on the bedrock. With available equipment, holes could not be drilled in bedrock in the valley bottom.

A profile along Conns Creek (fig. 38) shows the position of the water table in relation to channel and flood plain. The profile of the water table, based on a water-level measurement in a dug well about 1 mi above the confluence with Deberry Creek, and water levels in two wells at Seven Springs Hollow, shows that the water table declines beneath the channel, in the vicinity of the confluence with Deberry Creek. This confluence is the point at which the writers and a former landowner have observed dry-weather flow to cease numerous times. In addition, willow growth, an indicator of perennial surface or shallow subsurface water flow, is abundant upstream, but absent downstream from the Conns Creek-Deberry Creek confluence.

A cross section of the valley at Seven Springs Hollow (fig. 38) shows the decline in water level between two wells at the edge of the flood plain and the projected altitude of the water table beneath the flood plain. These data suggest that the water level is about 10 to 20 ft below the bedrock surface in the lower reach of Conns Creek, near Seven Springs Hollow.

The streams and gulleys tributary to the main stem of Conns Creek, at and below the Roubidoux-Jefferson City contact, exhibit very poor channel development. No sustained flow after rainfall is indicated or was observed. Vegetation growing in the channel, very little to no sorting of alluvial fines, and very weak channel development are indicators of vertical water loss from the alluvium into the underlying bedrock.

The water-holding capacities of six farm ponds and small lakes in the uplands bordering Conns Creek, and stream inflow characteristics before and after rainfall were observed during the period of investigation. None of the lakes or ponds maintained stable water levels within several days after inflow. One small lake has a drainage area of 330 acres, yet had no inflow and was dry during a period when heavy rainfall had produced considerable runoff in Conns Creek and Deberry Creek.

In the gaining reaches of Conns and Deberry Creeks, water is discharged into the stream system through springs and seeps and contributes to perennial streamflow. In the losing reaches of the two creeks, the general absence of springs and seeps indicates that the water percolating into the soils and

TABLE 10

Valley cross sections in Conns Creek Basin, June 6-10, 1977 (see fig. 37 for location of cross sections)

Flight Auger Boring

Section 1. Average elevation 790 ft above National geodetic vertical datum of 1929

Hole no.	Location	Depth (ft)	Description of material
1	100 ft north of channel	0-4.5	Silt
		4.5-7	Gravelly clay
		7-9	Bouldery silt
		9-14.5	Boulders; gravel (sandstone?)
		14.5	Dolomite - damp
2	250 ft north of channel	0-2	Silt
		2-12	Gravel; boulders; clayey (dry)
		12	Refusal on boulders (wet)
3	300 ft north of channel	0-3	Silt
		3-15	Gravel (clayey)
		15	Boulders
		15-16	Dolomite - soft (wet)
4	500 ft north of channel	0-2	Silt
		2-14	Gravelly, silty clay
		14-15	Hard (chert?)
		15-17.5	Soft dolomite - dry
5	700 ft north of channel	0-15	Brown silty clay
		15-23	Gravelly clay - stiff - plastic
		23-24	Chert bed
		24	Refusal
6	850 ft north of channel	0-2	Silt
		2-9	Gravelly clay (some lenses of gravel)
		9-21	Stiff, dry clay (no gravel)
		21-24	Gravel and boulders
		24	Refusal (probably chert zone)

Section 2. Average elevation 800 ft above National geodetic vertical datum of 1929

Hole no.	Location	Depth (ft)	Description of material
1	Channel bottom	0-4	Gravel
		4	Dolomite (dry)
2	150 ft south of channel on low terrace	0-10	Brown sandy silt
		10-10.5	Gravelly clay
		10.5-11	Dolomite (dry)
3	300 ft south of channel	0-7	Brown sandy silt
		7-8	Boulders
		8	Dolomite (dry)
4	400 ft south of channel	0-3	Brown silt
		3-7	Gravel (dirty)
		7-9	Silt, brown, dry
		9	Dolomite (small amount of water; 100 ft to south valley wall)

Table 10 (continued)

Flight Auger Boring

Section 3. Average elevation 810 ft above National geodetic vertical datum of 1929

Hole no.	Location	Depth (ft)	Description of material
1	170 ft south of new channel (bedrock on north slope of channel)	0-7	Boulders, gravel (dry)
		7	Refusal on chert
2	320 ft south of new channel	0-7	Boulders, gravel (dry)
		7	Dolomite (dry)
3	520 ft south of new channel in old channel	0-5	Gravel (wet but no free water)
		5	Dolomite
4	630 ft south of new channel	0-5	Boulders, gravel (dry)
		5-7	Large boulders
		7	Dolomite, fine grained (dry)
5	780 ft south of new channel	0-4	Brown silt
		4-5	Gravel (dry)
		5-9	Silty, sandy clay
		9-12	Gravelly clay
		12-14	Boulders
		14	Dolomite (dry)
6	980 ft south of new channel (75 ft to south valley wall)	0-2	Silt
		2-10	Gravelly, bouldery (dry)
		10-12	Brown silty, sandy clay (plastic)
		12-14	Boulders, gravel
		14	Refusal on chert

Section 4. Average elevation 830 ft above National geodetic vertical datum of 1929

Hole no.	Location	Depth (ft)	Description of material
1	50 ft south of channel	0-10	Silty, gravelly clay
		10-11	Dolomite; water (water rose to 7 ft below land surface in 1 hour; same at 24 hours)
2	200 ft south of channel	0-6	Hard, dry, gravelly silt
		6-10	Soft-wet gravelly clay (water)
		10-12	Dolomite (250 ft north of south valley wall)
3	150 ft north of channel	0-6	Silty; sandy gravelly clay
		6-8	Gravel and bouldery clay (water)
		8	Dolomite
4	350 ft north of channel	0-7	Coarse boulders, minor gravel
		7	Refusal on chert (dry)
5	500 ft north of channel	0-5	Bouldery; gravelly (dry)
		5	Refusal on chert

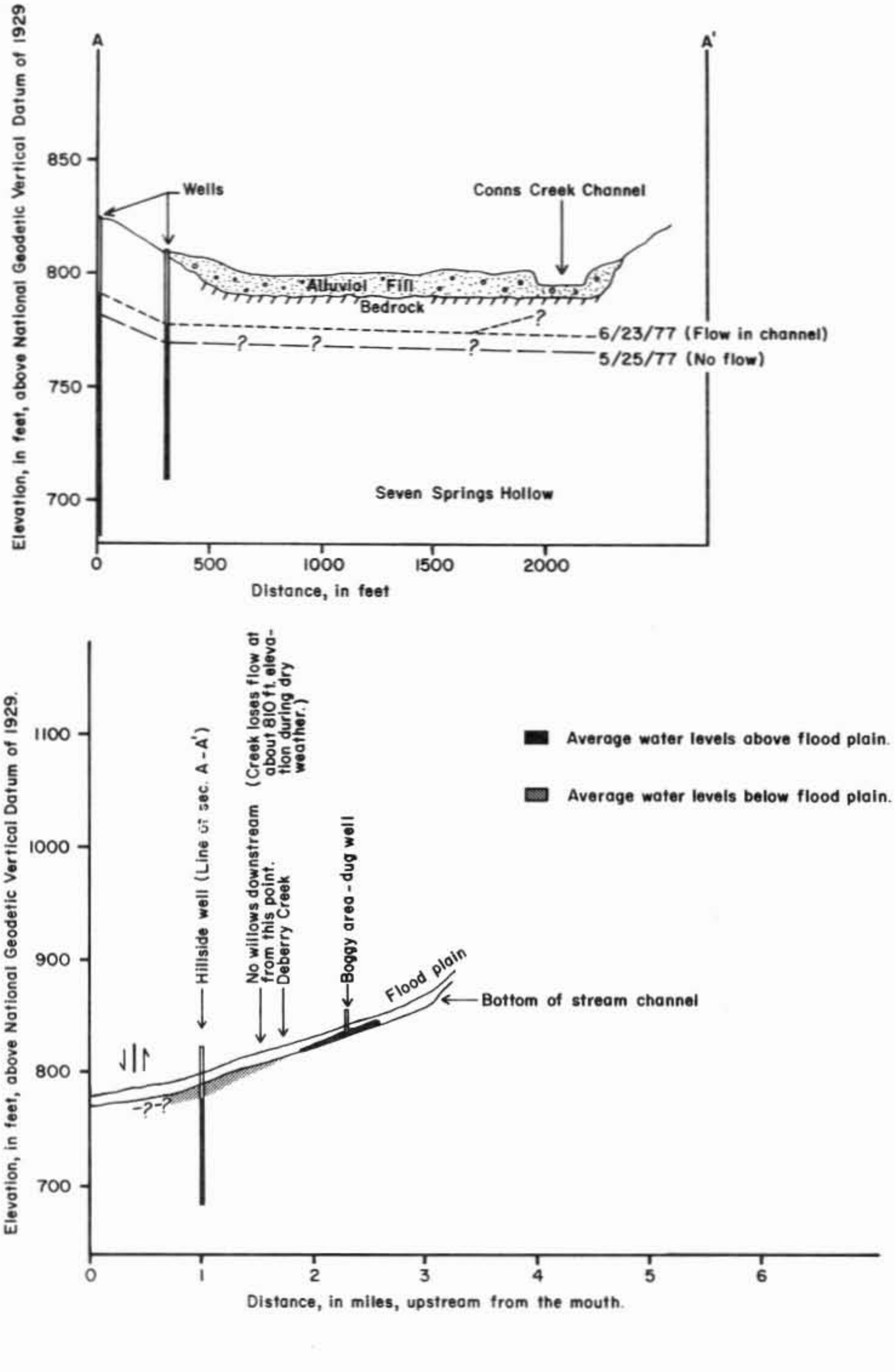


Figure 38. Profile and cross-section of Conns Creek showing groundwater-surface-water relationships.

bedrock of the Roubidoux Formation enters the valley as groundwater flow.

The total flow that the shallow bedrock in the valley bottom can transmit can be estimated from discharge observations. Figure 28 shows the flow pattern during a seepage run on April 1, 1976, when the loss was 8.2 ft^3/s in the lower reach of the creek. On another occasion, March 31, 1977, Conns Creek flowed continuously, headwaters to mouth. Streamflow measurements on the main stem were as follows: 10.5 ft^3/s, 100 ft downstream from the junction with Deberry Creek; 8.5 ft^3/s, 100 ft upstream from the mouth of Seven Springs Hollow; and 0.5 ft^3/s, near the mouth of Conns Creek. The capacity of the subsurface bedrock conduits, therefore, is estimated to be about 8 to 10 ft^3/s.

SUMMARY AND CONCLUSIONS

1. Using most of the available hydrologic data, the authors classified areas of recharge and discharge along streams in the three-basin region.
2. The evaluation of available methodology for hydrologic analysis in carbonate terranes led to the general conclusion that a combination of methods will always be needed; no single method can completely define the hydrologic conditions.
3. The most important controlling factor on the hydrology of Ozark basins is the amount and type of rock structural deformation. Northwest-trending faults are older than northeast-trending faults; hence, there has been more time for development of northwest-trending solution channels.
4. Reconnaissance geologic mapping should be available early in a project in order to determine where detailed mapping may be helpful when hydrologic data reveal an anomalous condition.
5. An appraisal of the differences in elevation between streams in adjacent basins offers definite clues to the flow characteristics of the entire system.
6. The latest 7½-minute topographic maps were extensively used in studying the hydrology of the area. Field observations showed that the actual incidence of perennial and intermittent streams in the tributary areas may differ from that shown on the maps.
7. A study of groundwater levels, in conjunction with other hydrologic data, can define areas of significant recharge and discharge.
8. The classic concept of a water table is approximated only along some of the perennial streams, such as Niangua River and Osage Fork, and rarely along others, such as Goodwin Hollow, where the aquifer is extremely heterogeneous through dissolution.
9. Except for small declines at municipal well sites, the potentiometric surface has changed very little in the past 30 to 40 years.
10. In upland recharge areas, depth to water increases markedly with well depth, whereas in discharge areas water levels in deep wells are only a little higher than in shallow wells.
11. In wells deeper than 400 ft, water-level elevations are more uniform than in shallower wells.

12. It is not advisable to dispose of sewage or industrial waste in streams or construct impoundments in valleys where groundwater levels are anomalously deep. Water-level elevations should be compared with streambed elevations in order to detect stream reaches where surface flow is lost to bedrock.

13. Where surface-water data are lacking, analysis of groundwater levels may lead investigators to predict where perennial flow might begin. Abnormal decline in groundwater levels along a stream valley may indicate streamflow loss, suggesting solution along zones of intense fracturing. Adjacent basins should then be considered areas of possible resurgence.

14. Well depths necessary for adequate water supplies are more uniform in valleys than uplands, a correlation related to the premise that valleys are zones of weakness and the lines of least resistance for draining an area; thus, they are the locus of greater intensity of fracturing and permeability.

15. Yields of wells completed in all formations above the Potosi Dolomite range from 9 to 35 gpm; however, a few wells reaching the Gunter Sandstone Member, at the base of the Gasconade Dolomite yield 100 gpm. Yields of wells completed in the Potosi Dolomite range from 100 to 750 gpm. Penetration of formations below the Potosi does not improve yield.

16. Studies of potentiometric maps, streamflow patterns, and geology are inadequate to pinpoint areas of resurgence of water from losing streams in carbonate-rock terrane. Groundwater tracing showed that upper Dry Auglaize Creek in Grandglaize Creek basin is one of the sources of recharge to Sweet Blue and Hahatonka Springs, in the Niangua River basin. The travel rate measured approximately 0.4 to 0.6 mi/d. The direction of dye travel showed that geologic structure strongly influences direction of groundwater movement.

17. Measurement of streamflow at numerous sites during a short period of time (seepage runs) is one of the most important available methods in studying the hydrology of carbonate terranes. Seepage-run data collected in the winter and spring (during periods when there is no storm runoff) can supply valuable information about losses in stream reaches normally dry during summer and fall.

18. Stream profiles are generally concave, but irregularities in short reaches may have lithologic or stratigraphic significance. Some irregularities are due to faults that may abut strong and weak beds; others may result from substantial inflows or losses of water.

19. Analysis of flow lines on the potentiometric map shows that the principal drainage divide between the Osage Fork flowing to the east, and Niangua River and Grandglaize Creek flowing to the north approximates the groundwater divide. Within these two systems, however, are numerous groundwater diversions between subbasins. In a carbonate terrane subject to a long period of dissolution resulting in considerable topographic relief, groundwater and surface drainage divides become less conformable.

20. The engineering geology study in Conns Creek basin was useful in relating a site study to the broader

hydrologic relationships of an entire basin.

21. Ozark soils are 40 ft or more thick in many places and store large quantities of water. In future studies, more comprehensive soil-thickness data should be used in hydrologic analyses of basins.

22. Identification of plants and plant assemblages common to gaining or losing stream reaches is useful in studying carbonate hydrology and aids in identifying areas of abrupt hydrologic changes.

23. Thermocouple measurement of winter soil temperatures showed that gaining stream valleys remained warmer than losing stream valleys. As a tool to support the findings from other lines of investigation, these data are useful, but the method is not as practical or as specific as other methods, such as surface-flow and groundwater-level measurements.

24. Only one water-quality sample was collected at most stream, well, and springflow sites selected for study. One set of samples can be useful in identifying areas with potential problems, or areas where more detailed data are needed, but several are required to explain data, from other lines of investigation, that suggest anomalous conditions.

25. Water analyses for wells showed gross correlation between areas of low mineralization and recharge areas on the one hand and high mineralization and discharge areas on the other.

26. Analyses of data from two wells in Bear Creek basin, one in a gaining reach and one in a losing reach, showed that wells in losing stream reaches are more susceptible to pollution than those in gaining reaches.

27. Analyses of single water samples from Sweet Blue and Hahatonka Springs in the Niangua River basin revealed low, but nevertheless abnormal, phosphorus contents such as might result from sewage-treatment plant effluent. Although these single samples were useful for hydrologic analysis, they would not have sufficed to identify the source of the phosphorus, without verification by groundwater tracing.

28. Land clearing for cattle grazing increased moderately between 1941 and 1970. Between 1970 and 1975, the cattle population increased 45 percent, resulting in extensive land clearing. The scant streamflow and sediment data available preclude an analysis of the effect of land clearing on stream characteristics.

29. Drainage density may not be helpful as a predictive hydrologic tool in carbonate terrane for the following reasons:
    a. There is excessive scatter in graphical plots of drainage density versus the 7-day Q_2, indicating that there is little relationship between drainage density and low-flow characteristics.
    b. Considerable manual labor is required to compute drainage density from topographic maps.
    c. Field work is required after drainage-density computations are completed, in order to answer the most important question: Is a stream gaining or losing flow?
    d. Other methods, considered more reliable, are available.

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Figure 4. Geologic Map of the Niangua River, Osage Fork and Grandglaize Creek basins.